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EV AGGREGATES VALUE CHAIN IN INDIA

ANALYSIS AND ROADMAP FOR ACCELERATING E-MOBILITY TRANSITION

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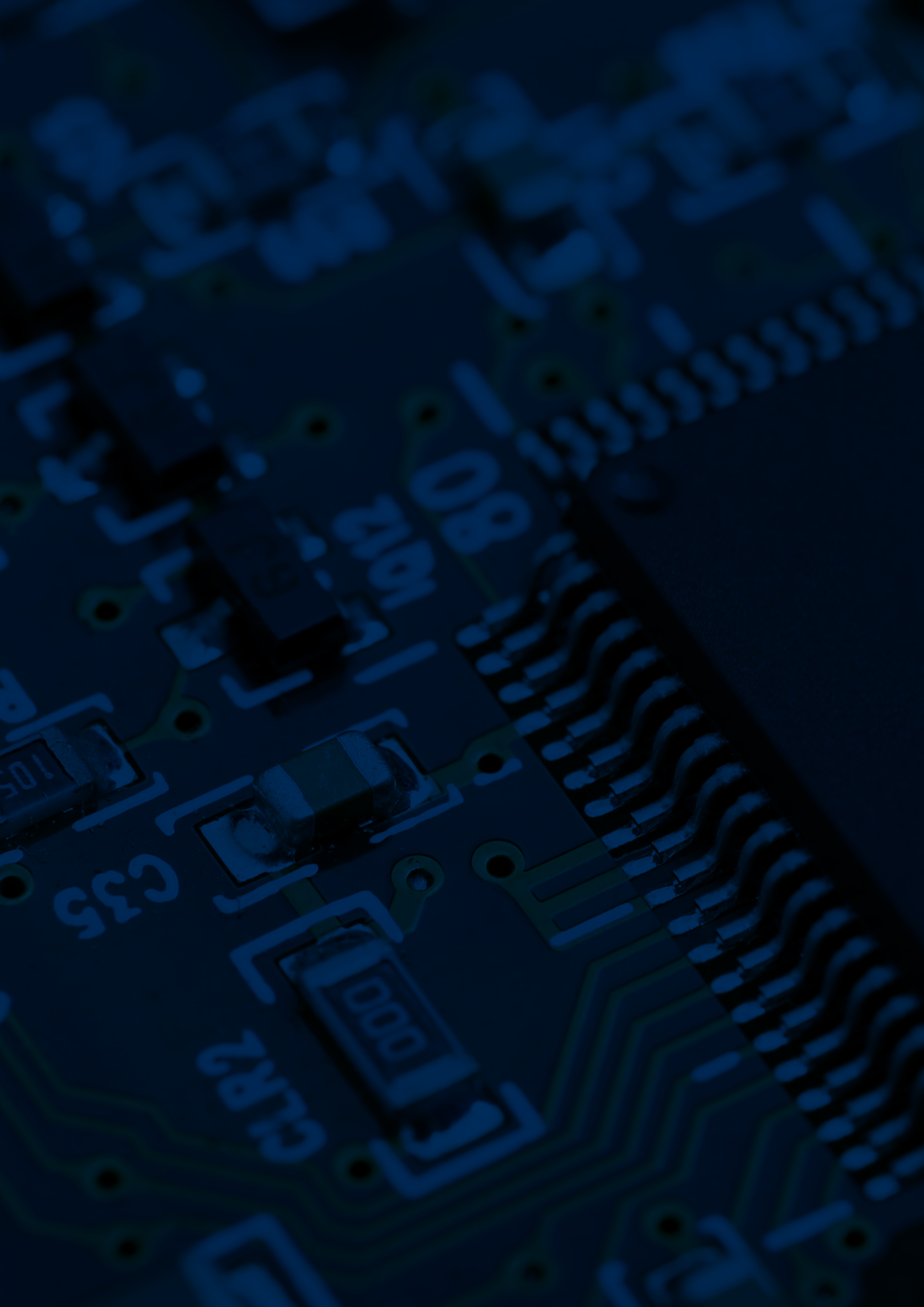

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VOLUME I

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ABSTRACT

The automobile industry contributes 49% of India's manufacturing GDP. It is a key driver of economic growth and development. Rising income and rapid urbanization, combined with improved customer choice are expected to further boost the outlook. The industry is, however, at the cusp of a significant transition, driven by technological, environmental, and social forces. Therefore, it will be critical to understand the emerging environment, adapt its strategies, and make investments to integrate with global value chains.

India's leadership to address the climate change challenge and its commitment to improving the quality of life means that the automobile industry will need to enhance its focus on sustainability. Transition to low and zero emission vehicles is therefore a key priority. E-mobility emerges as a natural and strategic choice given multiple benefits including energy security, improved air quality and advancing public transport goals.

The government has articulated a vision of 30% EV market share by 2030. Several programs and schemes have been launched to promote electric mobility and to support the evolution of a robust ecosystem. While the industry must rapidly adapt, the transition provides an opportunity to become a global manufacturing hub by fostering a robust domestic supply chain.

This study is focused on the E-mobility transition, a culmination of technological, environmental, and social considerations. While the focus was on the key components (power train, power electronics and related software) of heavier vehicles, it was evident that a three-sixty-degree view was essential, given the interconnectedness of the value chain.

The initial part reviews the current EV landscape, but the focus was towards looking into the future. Medium and long-term scenarios are developed to develop estimates of potential sales and market for various products and components. We also look at the current localisation levels for the mentioned components and highlight the challenges as well as the opportunities. This will be useful to the industry players such as OEMs, component manufacturers and suppliers, as well as the investment community.

Based on the demand drivers, a review of planned investments, analysis of the policy and institutional framework and in consultation with industry experts, a roadmap was prepared to enable and accelerate the E-mobility transition. It provides recommendations across a range of areas including policy, finance, market, research, skill enhancement and others. It can be used by stakeholders to formulate policies, strategies and investment analysis, research and skill development plans.

Four industry workshops conducted in different parts of the country evinced a strong interest in the subject and continued engagement for implementing the recommendations. Since the roadmap identifies short term as well as medium term recommendations, it will enable stakeholders to work collaboratively over a period of time. An Industry Working Group is proposed to take forward various recommendations.

“If you want to leave your footprints on the sands of time, do not drag your feet.”

A.P.J. Abdul Kalam, Wings of Fire

Source: PIB

FOREWORD

Dr. Hanif Qureshi, IPS
Additional Secretary
(Automobile Division)

सत्यमेव जयते

आज़ादी का अमृत महोत्सव

भारत सरकार
भारी उद्योग मंत्रालय
Government of India
Ministry of Heavy Industries

Dated: 20.08.2024

India is at the cusp of a transformative era. As one of the fastest-growing economies, our nation embodies entrepreneurial energy, technological strength, and rising global influence. With a rapidly expanding economy fueled by a vast consumer base and a competitive services sector, India is also focused on bolstering its manufacturing sector—a critical driver of jobs and growth.

The automobile industry, a cornerstone of Indian manufacturing, is globally competitive across many segments. As incomes rise and urbanization accelerates, this sector is poised for even greater global attention. India's leadership in climate action, particularly in decarbonizing transportation, is well-recognized. The shift to electric mobility is not only a strategic imperative but a vast economic opportunity, driving innovation in manufacturing and environmental stewardship.

The Government's commitment exemplifies the path for sustainable mobility and long term viability. Programs like the National e-Bus Programme and the PM E-Bus Sewa Scheme underscore our dedication to electrifying public transport, with thousands of electric buses set to be deployed nationwide.

Initiatives such as the FAME schemes, Production Linked Incentive (PLI) programme, and the National Electric Mobility Mission Plan (NEMMP) highlight our proactive stance in fostering a thriving EV ecosystem. These policies incentivize EV adoption and support the development of a robust domestic manufacturing base for EV components.

This report captures the EV value chain in the Indian market, emphasizing the need for coordinated policy implementation, industry collaboration, academic research, and technological innovation. India's journey towards electric mobility is a testament to our commitment to sustainable development and dynamic economic growth. Building a strong EV ecosystem will unlock significant opportunities, with collaboration among government, industry, and academia being key.

Together, we can steer India toward a green future where innovation and sustainability drive industrial and environmental leadership.

20/8

(Dr. Hanif Qureshi)

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ACRONYMS

2W	Two-Wheeler
3W	Three-Wheeler
4W	Four-Wheeler
AAT	Advanced Automotive Technology
ABS	Anti-lock Braking Systems
AC	Alternative Current
ACIM	Alternate Current Induction Motor
ACC	Advanced Chemistry Cell
AD	Autonomous Driving
ADAS	Advanced Driver Assistance Systems
AFM	Axial Flux permanent Magnet motors
ARAI	Automotive Research Association of India
ARIMA	Auto-Regressive Integrated Moving Average
ARIMAX	Auto-Regressive Integrated Moving Average with exogenous variables
ASP	Average Selling Price
ATMP	Assembly, Testing, Marking, and Packaging
BAU	Business As Usual
BLDC	Brushless Direct Current
BMS	Battery Management System
BOM	Bill Of Material
BS	Bharat Standard
CAGR	Compound Annual Growth Rate
CASE	Connected, Autonomous, Shared, Electric
CBU	Completely Built-Up
C2S	Chip to Start-up
CE	Circular Economy
CEM	Clean Energy Ministerial
CESL	Convergence Energy Services Limited
CKD	Completely knocked down
CNG	Compressed Natural Gas
CO2	Carbon Dioxide
COVID-19	Coronavirus Disease
CRNO	Cold Rolled Non-Grain Oriented
CV	Commercial Vehicle
CY	Calendar Year
DC	Direct Current
DCU	Domain Control Unit
DPDPA	Digital Personal Data Protection Act
DVA	Domestic Value Addition
Dy	Dysprosium
E2W	Electric Two-Wheeler
E3W	Electric Three-Wheeler
E4W	Electric Four-Wheeler
ECU	Electronic Control Unit
E/E	Electrical and Electronics
ER&D	Engineering, Research, and Development
EU	European Union
EV	Electric Vehicle
FAME	Faster Adoption & Manufacturing of Electric Vehicles in India
FCEV	Fuel Cell Electric Vehicle
FY	Fiscal Year
GaN	Gallium Nitride
GARC	Global Automotive Research Centre
GBP	Great British Pound
GCC	Gross Cost Contract
GDPR	General Data Protection Regulations
GEMRIX	Global Electric Mobility Readiness Index
GHG	Green House Gas
GST	Goods and Services Tax
H2ICE	Hydrogen Internal Combustion Engine
HGV	Heavy Goods Vehicle
HMI	Human Machine Interface
HV	High Voltage
IC	Integrated Circuit
ICAT	International Centre for Automotive Technology

IICT	International Council on Clean Transportation
ICE	Internal Combustion Engine
IGBT	Insulated-Gate Bipolar Transistor
IR	Indian Railways
IVI	In-Vehicle Infotainment
KII	Key Informant Interview
LCV	Light Commercial Vehicle
LGV	Light Goods Vehicle
LIDAR	Light Detection and Ranging
LV	Low Voltage
MCU	Motor Control Unit
MD/HDT	Medium and Heavy-duty Electric Trucks
MGV	Medium goods vehicle
MHI	Ministry of Heavy Industries
MnT	Million Tonnes
MoHUA	Ministry of Housing and Urban Development
MoRTH	Ministry of Road Transport and Highways
MoSFET	Metal-Oxide-Semiconductor Field-Effect Transistor
MSME	Micro, Small, and Medium Enterprises
NATRiP	National Automotive Testing and R&D Infrastructure Project
NdFeB	Neodymium-Iron-Boron
NdPr	Neodymium and Praseodymium
NEBP	National Electric Bus Programme
NEMMP	National Electric Mobility Mission Plan
NGHM	National Green Hydrogen Mission
NIP	National Infrastructure Pipeline
NVH	Noise, vibration, harshness
OBC	Onboard Charger
ODM	Original Design Manufacturers
OEM	Original Equipment Manufacturer
OSAT	Outsourced Semiconductor Assembly and Test Facility
OTA	Over-The-Air
PCB	Printed Circuit Board
PDU	Power Distribution Unit
PE	Power Electronics
PLI	Production Linked Incentives
PM	Permanent Magnet
PMP	Phased Manufacturing Programme
PMSM	Permanent Magnet Synchronous Motor
PMSynRM	Permanent Magnet Synchronous Reluctance Motor
PPP	Public Private Partnership
PSM	Payment Security Mechanism
PT	Powertrain
PTA	Public Transport Authorities
PV	Passenger Vehicle
QCO	Quality control orders
RADAR	Radio Detection and Ranging
R&D	Research and Development
RE	Rare Earth
REE	Rare Earth Element
SDV	Software Defined Vehicles
SIAM	Society of Indian Automobile Manufacturers
SiC	Silicon Carbide
SKD	Semi knocked down
SPECS	Scheme for Promotion of Manufacturing of Electronic Components and Semiconductors
SRM	Switched Reluctance Motor
STU	State Transport Undertaking
SynRM	Synchronous Reluctance Motor
TCO	Total Cost of Ownership
TFM	Transverse Flux Motors
TMS	Thermal Management System
Tr	Terbium
VCU	Vehicle Control Unit
ZET	Zero Emission Truck
ZEV	Zero Emission Vehicle
ZEVTC	Zero-Emission Vehicle Transition Council

1. INTRODUCTION AND OBJECTIVES

The auto industry will change more in the next five to ten years than it has in the last 50.

Mary Barra

Source: RTI

1.1 India's Automobile Industry: An Overview

India is the world's fifth-largest economy with a GDP of USD 3.7 trillion in FY23 and the largest economy by purchasing power parity (PPP). On per capita income basis, India is ranked 138th by nominal GDP, and 125th for PPP-based GDP (IMF, 2023). It is the world's fourth-largest consumer market with domestic consumption accounting for about 70% of the GDP (WorldBank, 2022).

India is keen to expand its manufacturing sector, particularly to increase livelihoods. Crisil's recent outlook highlights the pivotal role of the manufacturing sector in growth (crisil, 2024). The automobile industry contributes 49% of the manufacturing gdp and is a key driver of the economic growth and development (pib, 2019). The sector provides direct and indirect employment to millions of people, with estimates ranging from over 19 million (pib, 2023) to 37 million people (ficci, 2019).

The industry demonstrated robust growth and ranked fourth largest globally by production in FY22, and the third largest by sales in FY23 (OICA, 2022). It is the largest producer of three-wheelers and tractors, and fourth largest in the world for passenger vehicles (Figure 1.1).

Rising income and rapid urbanization, combined with improved customer choice are expected to further boost the outlook. An increasing interest from Indian companies to expand their portfolio and international companies to enter the market, reflects India's increasing importance in the global automotive landscape.

Over the last ten years, India has emerged as one of the preferred locations for manufacturing high-quality automotive components (PIB, 2023). It has manufacturing capabilities in products such as electronic power steering, airbag electronics, anti-lock braking system, and fully automatic temperature control systems. Further, growing numbers of domestic and global automobile OEMs (Original Equipment Manufacturers) have increased local sourcing of components (McKinsey & Company, 2018).

The auto components industry was valued at USD 69.7 Billion in 2023 and has been growing at a Compound Annual Growth Rate (CAGR) of 17% over the last three years (ACMA, 2023). An increased focus on localisation and supportive government schemes are expected to increase the output to USD 300 Billion by 2026 (Invest India, 2024).

India's leadership to address the climate change challenge and its commitment to improving quality of life means that the industry will need to enhance focus on sustainability as it looks towards the future. A key mandate towards sustainability is to transition towards low or zero emission vehicles. E-mobility is a key enabler of sustainability and there are multiple drivers to India's push towards e-mobility.

Figure 1.1: India's global ranking in auto manufacturing (2022-23)

Vehicle-type	Global Ranking (by Production)	Global Ranking (by Sales)
Three-wheelers (3W)	Rank 1	-
Tractors*	Rank 1	-
Two-wheelers (2W)	Rank 2	-
Passenger Vehicles (PV)	Rank 4	Rank 2†
Commercial Vehicles (CV) (including trucks)	Rank 6	Rank 4†

*Source: Compiled from the 324th Report of the Parliamentary Standing Committee (2023); * The Hindu Business Line (2023); and † TheGlobalEconomy.com (2024)*

1.2 Imperatives for E-Mobility Transition

India's e-mobility transition is driven by several economic and social considerations. These include:

i. **Air Quality Considerations:** India is urbanising rapidly, and the quality of air in Indian cities needs to be improved to reduce negative impacts on health. A study conducted jointly by the Ministry of Health and Family Welfare, Indian Council for Medical Research, UNEP etc. suggested that air pollution was responsible for 1.7 million i.e. 18% of total deaths in 2019 (ICMR, 2020). Further, the economic loss of output from premature deaths and morbidity from air pollution was estimated to be INR 2.6 trillion, equivalent to 1.4% of GDP in 2019. The National Clean Air Programme (NCAP) was launched with the aim to implement comprehensive mitigation measures for the prevention, control, and reduction of air pollution in 132 cities through multi-sectoral, inter-state, and inter-city coordination (Lok Sabha, 2022). One of the key rationales for the Faster Adoption and Manufacturing of (Hybrid &) Electric Vehicles (FAME) Scheme (Phase II) was to enable improvements in the air quality (PIB, 2023).

ii. **Economic Imperative:** As mentioned in section 1.1 above, the size and importance of the automobile industry for India's manufacturing sector and overall economy requires a strategic view of the e-mobility opportunity. Given that e-mobility is emerging as a global trend along with an increasing desire for companies and countries to diversify supply chain, domestic and international priorities are well aligned.

iii. **Energy Security:** India imports more than 85% of crude oil, which accounted for 25% of the total merchandise imports (Ministry of Petroleum and Natural Gas, 2024). At the current rate, crude oil imports may grow by over four-times by 2050 (PPAC, 2023).

In addition to the above, e-mobility is also expected to support achievement of India's climate change goals. There are several decarbonization initiatives in the transport sector, which are briefly outlined in the next section.

1.3 Transport Decarbonization Initiatives

India aims to achieve net-zero emissions by 2070 (PIB, 2023). The transport sector accounted for 9.7% of India's GHG emissions (Parliamentary Standing Committee, 2023). Therefore, decarbonization of the sector will be a key driver of the technology, policy, and market transformation. One key strategy for decarbonization is the deployment of zero-emission vehicles (ZEV). The adoption of 'Panchamrit', referring to the five (5) clean fuels, namely, hydrogen, ethanol, bio diesel, gas, and electric vehicles (EV), is seen as a pathway towards transport decarbonization.

To fast-track electric mobility, the government has articulated a vision of 30% EV market share by 2030 (PIB, 2023). It has a potential to reduce 16 Million tons of CO2 emissions, 17% reduction in particulate matter (PM) and nitrogen oxide (Nox) emissions, and crude oil import by 15%, accruing an annual saving of USD 14 Billion (CEEW, 2020).

India also signed the United Nations Climate Change Conference (COP26) Zero-Emission Vehicle Transition Council (ZEVTC) declaration that requires all new car and van sales to be zero-emission by 2040 (NITI Aayog, 2022).

Further, there is an increasing acknowledgement of the need to expand public transport. E-mobility presents an opportunity to leapfrog to zero emission, low carbon pathway. The National e-Bus Programme (NeBP) and the PM E-Bus Sewa Scheme are steps in this direction. These aim to accelerate electrification of buses by deploying 50,000 electric buses by 2027 (PIB,

Figure 1.2: India's transport related decarbonisation initiatives

Road Transport

Ambition for National EV-deployment under the EV30@2030
The Government of India (GoI) envisions 30% EVs market share by 2030 (PIB, 2023).

Electrification of Buses under the National e-Bus Programme (NeBP)
NeBP aims at deploying 50,000 electric buses by 2027 (PIB, 2023).

The PM E-Bus Sewa Scheme aims for 10,000 electric buses in PPP model (PIB, 2023).

Charging Infrastructure

Initial focus on 9 mega-cities namely Surat, Pune, Ahmedabad, Bengaluru, Hyderabad, Delhi, Kolkata, Mumbai, and Chennai (PIB, 2022).

The public-sector Oil Marketing Companies (namely, IOCL, BPCL, and HPCL) to establish 22,000 charging stations in prominent cities and highways (PIB, 2022).

Railways

The Indian Railways (IR) aims to be a net-zero carbon emitter by 2030 (PIB, 2023).

The National Rail Plan (NRP) targets increasing the modal share of railways (from 27% in 2022) to 45% of freight traffic by 2030 (PIB, 2022).

Aviation

Indian carriers are expected to be part of ICAO Carbon Offsetting & Reduction Scheme for Aviation (CORSIA) from 2027 onwards (PIB, 2023).

Carbon Accounting and Reporting framework for Indian Airports has been standardised and all airports are encouraged to move towards carbon neutrality (PIB, 2023).

Shipping

The 'Maritime India Vision 2030' aims to make India the 'Global Hub for Green Ship' building (PIB, 2023).

India has also implemented all MARPOL (International Convention for Prevention of Pollution from Ships) regulations pertaining to carbon emissions from Indian ships (PIB, 2023).

Source: Government of India (Press Releases via PIB)

2023), and another 10,000 electric buses under the public private partnership model (PIB, 2023), respectively.

India's overall net-zero target by 2070 does not include transport-specific pathways such as those articulated for the energy sector. However, various subsectors (roads, railways, airlines, and shipping) have articulated their respective targets and strategies, which are presented in Figure 1.2.

Given that numerous steps have been initiated, as outlined above, it is possible that India may adopt more formal targets for the transport sector in the future, similar those in advanced economies such as Europe. The European Union (EU) is targeting 100% zero-emission road mobility by 2035 and leads the global effort in decarbonising and e-mobility transition in the automotive sector. A landmark EU law requires cars and light commercial vehicles sold from the year 2030 onwards to have 55% lower CO2 emissions (compared to 2021 emission-levels), and all new cars from 2035 onwards to have zero CO2 emissions (European Parliament, 2022).

1.4 Government Policies for Electric Mobility

In 2013, the Government of India launched the National Electric Mobility Mission Plan (NEMMP) 2020. The plan aims to achieve national fuel security by promoting electric mobility. Under the NEMMP, fiscal and monetary incentives were offered with an intent of achieving sales of 6-7 million hybrid and electric vehicles year-on-year from the year 2020 onwards (BEE, 2022). Several policies and programes were launched under the NEMMP as briefly discussed below and further elaborated in chapter 2.

1.4.1 Central Government Policies and Programmes

The Government of India is promoting electric mobility through various initiatives like the Faster Adoption and Manufacturing of (Hybrid &) Electric Vehicles (FAME) - I and II, Production Linked Incentive (PLI) schemes, etc. The ecosystem has been further supported by issuing guidelines for charging infrastructure, including building codes, green license plates for EVs, etc. (WRI, 2021).

On the supply side, several policies encourage local manufacturing, including two Production Linked Incentive (PLI) schemes, introduced to boost domestic manufacturing of EVs and associated components. One scheme supported setting up competitive Advanced Chemistry Cell (ACC) battery manufacturing units, while the other focused on automobiles and auto components.

1.4.2 State-level Programmes and Initiatives

Each state offers different benefits for electric vehicles, however the policies for enhancing electric mobility fall into two broad categories: a) increasing EV adoption for their respective territories; and b) making the states preferred destination for EV and EV-component manufacturing.

Many large cities, like Ahmedabad, Surat, Pune, Delhi, Mumbai, and Chennai, have also established individual targets for e-Bus adoption (TUMI, 2023).

Therefore, the EV ecosystem benefits from initiatives and incentives at both the central and state government levels.

1.5 India's EV Sector and Market Trends

1.5.1 Demand Side

The EV industry is in its early stages of evolution but appears to be gathering momentum. The overall EV penetration in India was about 6.9% in CY24, compared to the average penetration of 17.3% for Asia in CY 22 (Business Standard, 2023). The Global Electric Mobility Readiness Index (GEMRIX) ranks India at 16th position in terms of EV readiness (Arthur D. Little, 2023).

India became the biggest market for E3Ws in 2023, overtaking China, and the second-largest electric 2W market globally. Increasing sales can be attributed to various factors, including financial incentives and the resulting lowering of ownership cost (IEA, 2024).

Between FY 19-24, EV sales grew at a CAGR exceeding 60% and crossed the threshold penetration of 5% by the end of 2023. This maybe a tipping point, signalling potential for mass adoption. Figure 1.3 and 1.4 present the details.

Cumulatively, around 3.7 Million EVs have been sold between FY19-24, of which 54% were two-wheelers (2Ws), 42% were three-wheelers (3Ws), 4% four-wheelers (4Ws), with Buses and Trucks comprising the remainder 0.5%. Annexure 1.2 includes detailed segment wise analysis of EV sales and penetration between FY19-24.

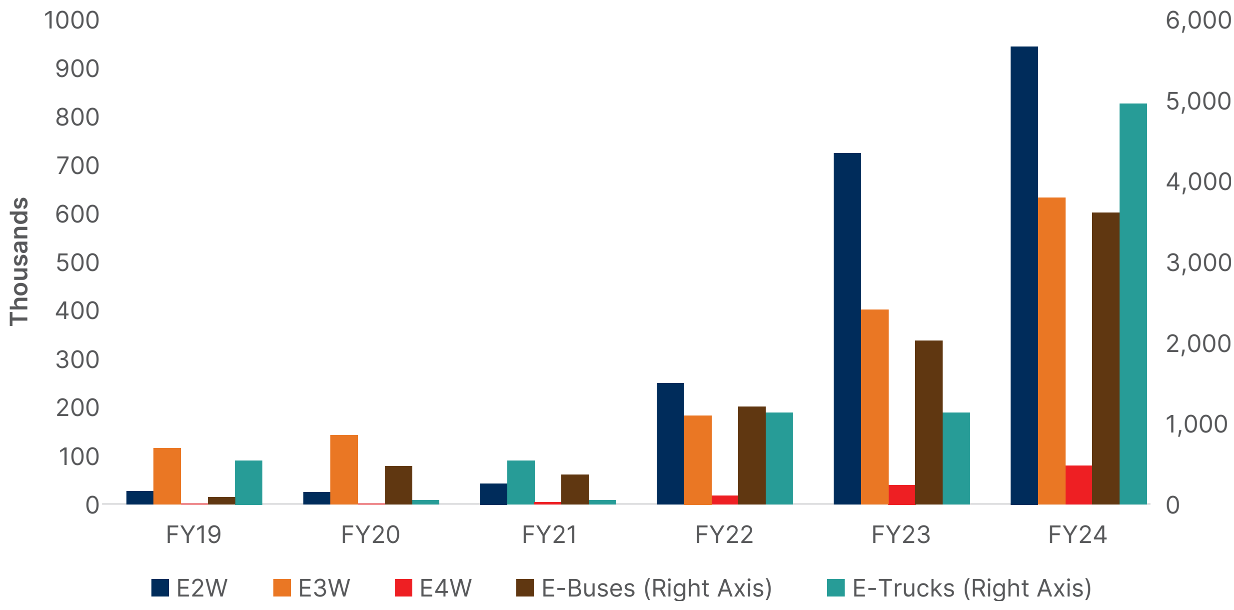
As per the Economic Survey 2023, sales will continue growing rapidly till 2030 with an expected CAGR of 49% and potentially exceed 10 million units (Economic Survey, 2023). Other estimates of future growth have been made by various organisations and were reviewed as a part of the development of sales scenario in this report. Chapter 3 of this report present these in detail.

1.5.2 Supply Side

On the supply side, EV components currently constitute a relatively small share (around 3%) of the overall auto component industry turnover (ACMA, 2023). It was worth around USD 536 Million in 2019 and akin to EV sales, market estimates project a rapid growth with P&S estimating a CAGR of 22% till 2030 (P&S Intelligence, 2020).

E-mobility transition will likely make some of the ICE (Internal Combustion Engine) components such as clutches, radiators, and gears, obsolete. These will be replaced with other components such as electric motors, batteries, inverters, etc. Component suppliers have started restructuring their businesses to accommodate EVs. However, a significant part of the near-term EV-demand may have to be met by imports and start-ups (Business Today, 2022).

Figure 1.3: Segment- wise EV sales between FY19 to FY24



Source: Vahan Dashboard
Note: E3W category includes E-Rickshaw, Bus category includes all types of buses.

Figure 1.4: Segment-wise EV penetration rate and sales growth

Segment	Sales Penetration FY24	CAGR (FY19-24)
E2W	5.4%	104%
E3W	54.3%	40%
E4W	1.8%	131%
E-Bus	4.0%	114%
E-Truck	0.5%	57%
Overall	**6.9%**	**63%**

Source: RTI Analysis based on Vahan Dashboard data

The growing share of EVs is a positive indicator for the automotive component manufacturing sector. The automotive industry has an opportunity to capitalise from the move towards e-mobility, by upgrading specific ICE components for EV applications and by innovating on specific EV components.

1.6 Scope and Approach

The study focuses on EV powertrain, power electronics, and related software, particularly for the heavier vehicle segment. A separate study on batteries is being conducted and hence excluded from the scope.

1.6.1 Objectives of the Study

The key objectives of this research include:

1. Assessing the landscape of the EV-component supply chain in India.
2. Identifying gaps in the EV-component manufacturing ecosystem.
3. Estimating EV sales and component market size for critical EV components.
4. Developing a roadmap for EV-component manufacturing.

1.6.2 Methodology

The study adopted a combination of approaches, including desk review, modelling, key informant interviews, and stakeholder consultations. These are described in Figure 1.5.

1.7 Structure of the Report

This report comprises of five chapters:

Chapter 1 provides the context to the study, key market trends and research objectives.

Chapter 2 presents EV-component landscape, including the market dynamics, drivers, and investment planned in the sector.

Chapter 3 presents the methodology and results of scenarios of EV sales and penetration for the

Figure 1.5: Research methodology

Desk Review	• Industry trends, EV landscape and ecosystem, etc. • International experience.
Scenario Development	• Modeling segment wise sales in medium and long-term • Developing segment wise EV penetration estimates
Industry Consultations	• 1-1 meetings with industry players across Chennai, Bangalore, Pune, and Delhi-NCR (refer Annexure 1.1).
Stakeholder Workshops	• Four stakeholder consultation workshops in Delhi, Pune, Bengaluru, and Chennai • Analysis and Roadmap presented in 1-1 meetings to NITI Aayog, MHI, CII and ACMA.
Final Report	• Final Report prepared, edited and designed.
Dissemination	• Knowledge sharing through launch at CII's Manufacturing Innovation Conclave 2024
Industry Working Group	• Formation of an Industry Working Group to carry forward the recommendations

Source: RTI

medium-term (2024-2030) and long-term (2030-2047), along with an analysis of the results.

Chapter 4 includes a deep dive on traction motors and power electronics, their cost structure, market size, localisation, and challenges on the supply-side. Circular economy strategies are also discussed briefly.

The final roadmap with specific recommendations is presented in Chapter 5.

Source: RTI

2. EV COMPONENT INDUSTRY LANDSCAPE

Never doubt that a small group of thoughtful, committed citizens can change the world; indeed, it's the only thing that ever has.

Margaret Mead

Source: RTI

This chapter provides an overview of the components industry including market dynamics, key market drivers, and investment commitments made by component manufacturers and OEMs.

2.1 Brief Overview of EV Components

An EV drivetrain has fewer, about 20 or so, moving parts compared to the 200 or so in a typical drivetrain for an internal combustion engine. EVs are therefore mechanically less complex compared to the latter. EVs have some components that are entirely new, though some ICE components can be used or adapted for EV applications. Fuel systems and exhaust system components are not needed in an EV, these are replaced with batteries and traction motors.

A battery provides the electric energy required to drive the traction motor, which in turn converts it into mechanical energy to move the vehicle. An inverter is required to convert the DC power to three-phase AC. DC-DC converter steps down 12V power to lower voltages required for systems such as lighting, infotainment, windows etc.

The addition of different components and evolving technology presents opportunities for new players to enter the segment and for the legacy ICE players to transform their business. Figure 2.1 presents an overview of the key components in the EV powertrain.

2.2 EVs- Cost Structure and Cost of Ownership

The cost structure of an EV can broadly be divided into four categories. Batteries account for the highest share (30-40%), followed by the powertrain and power electronics together accounting for 20-30%, while the chassis (20-25%) and the control systems (5-10%) constitute the rest. Although the cost proportions may vary slightly based on the sourcing strategy (imported versus domestically sourced), the typical share is presented in Figure 2.2.

Given the focus of the study on heavier segments, a comparison of the cost range and structure of E-buses is relevant and presented in the next section.

2.2.1 Comparative Analysis of Bus BOM

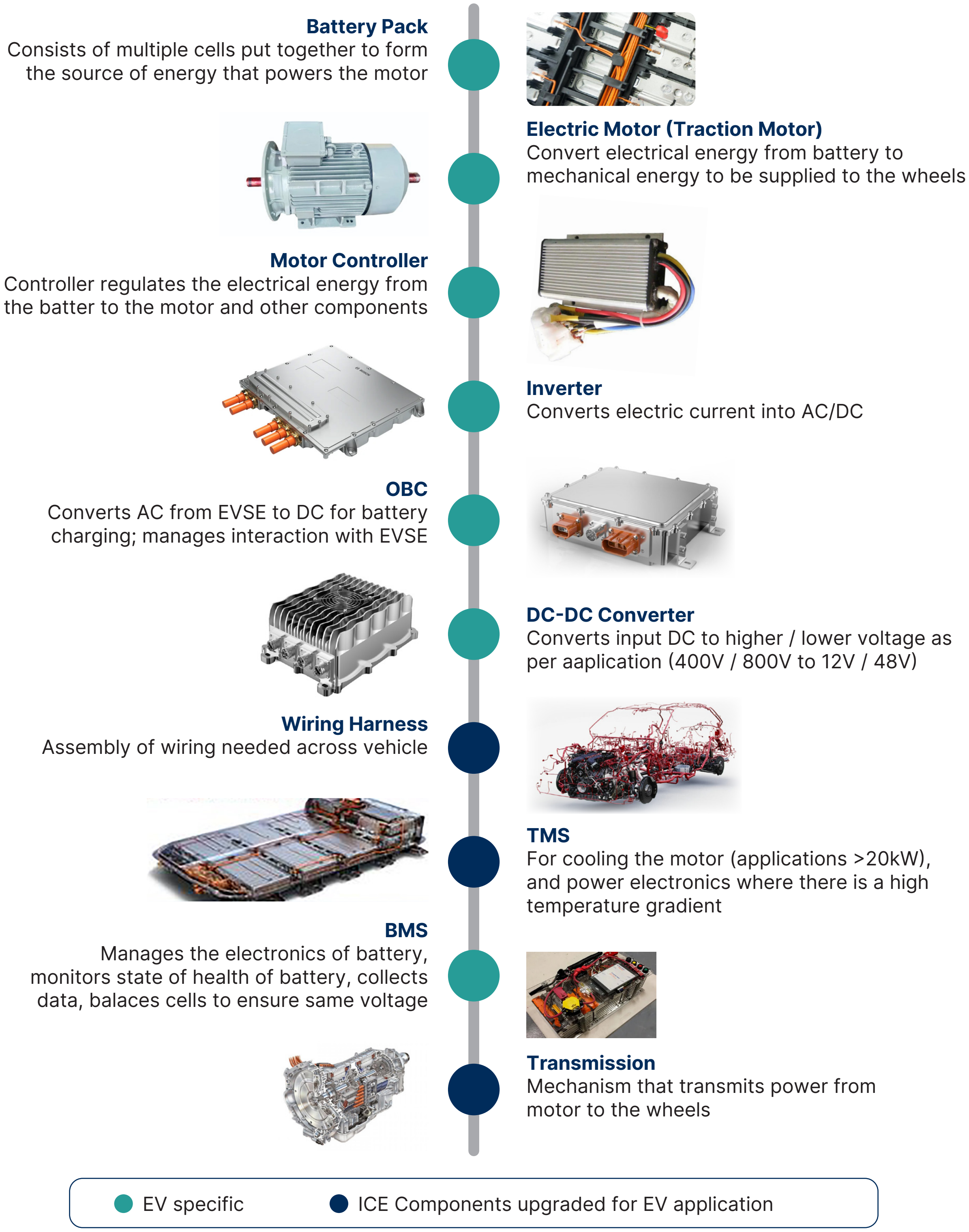
Figure 2.3 depicts the bill of material (BOM) comparison for an ICE and an electric bus. The share of drive transmission plus engine (35%) in an ICE bus is replaced by battery and related components (35%) in an electric bus. Powertrain and power electronics is the second biggest share in an e-bus, contributing about 25% of the total components. Collectively, battery, powertrain, and power electronics account for about 60%, while the rest is attributed to connectivity, chassis, and other body parts.

2.2.2 Comparative Analysis of Bus TCO

While the BOM is relevant for manufacturing, from customer perspective the Total Cost of Ownership (TCO) is a more relevant matrix. The TCO comparison for e-buses and diesel-run buses is presented in Figure 2.4. The analysis for an E-bus suggests that the upfront purchase cost, at about 73% of the total, has the highest impact on the TCO per km. On the other hand, operating costs, including maintenance, fuel, and staff costs, contribute to over 65% of the TCO for diesel-run buses. The gap in capital and maintenance costs reflect a difference of approximately INR 18 per kilometre in the total ownership costs, in favour of an E-bus. Decreasing battery prices are expected to further reduce the TCO of E-buses.

Lower TCO of E-buses was evident from the discovered price of E-buses in the tender issued by CESL. The per km rates were discovered to be lower than the prices of diesel and CNG buses, as presented in Figure 2.5.

Figure 2.1: Overview of EV components



Source: RTI

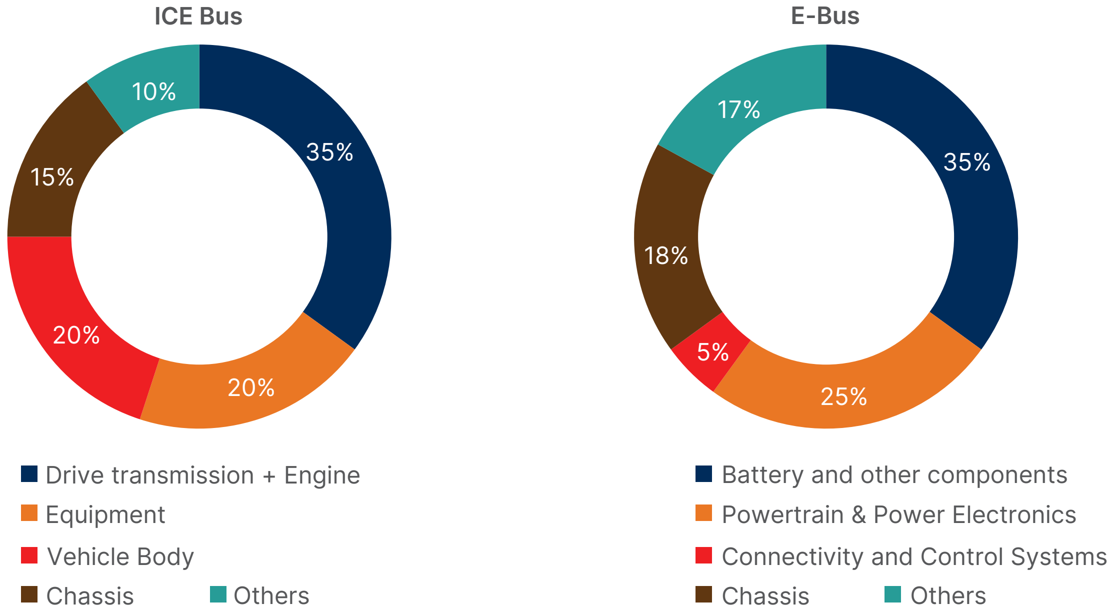
Image credits: Covestro, Inside EV, Desert cart, CETL motor, India Mart, EV Update, Embitel, CNET

Figure 2.2: Component-wise cost breakdown for EVs (indicative ranges)

EV Segment	E2Ws	E3Ws	E- cars	E- buses	E- trucks
EV Segment	E2Ws	E3Ws	E- cars	E- buses	E- trucks
Battery & related components	45-50%	35-40%	40-45%	30-35%	40-45%
Powertrain & power electronics	35- 40%	35-40%	25-30%	20-25%	20-25%
Chassis and other body parts	15-20%	15-20%	20-25%	30-35%	35-40%
Connectivity and control systems	3-5%	5-7%	7- 10%	5-7%	3-5%

Source: ACMA (2021), Expert interviews and analysis

Figure 2.3: ICE vs. Electric Bus Bill of Material (BOM) component-level breakdown



Source: ACMA (2021); Expert consultations

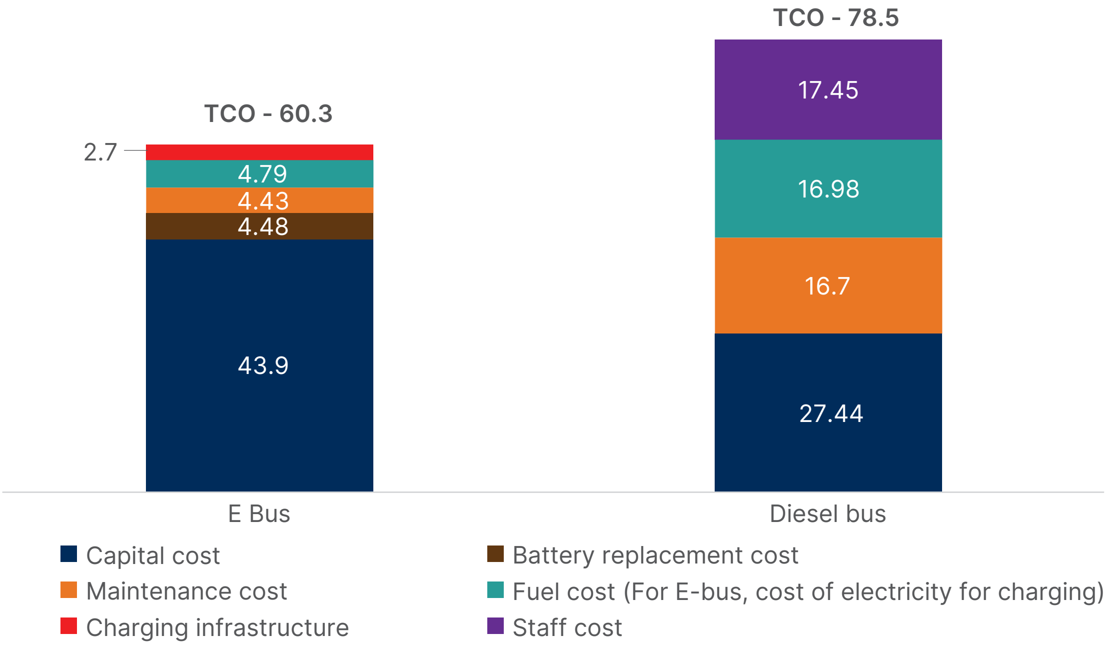
On average, the rates per km for E-buses as discovered in CESL tenders were found to be 27% lower than diesel buses and 23% lower than CNG buses (Figure 2.5). The minimum difference was 23% in case of a CNG bus (without subsidy), while the maximum was 35% in case of a diesel bus (with subsidy).

While the specific details of the recent tender issued by CESL in 2024 are not in public domain, it is understood that about 1400 buses were contracted by CESL for two states. A Payment Security Mechanism (PSM) is planned and the TCO of E-Buses is expected to be below diesel and CNG equivalents.

A recent analysis by Transit Intelligence revealed that TCO for 12m AC E-Bus, operating 500 km per day in contract carriage mode to be 12-15% lower compared to equivalent diesel bus. However, 12 m Non-AC E-bus operating 400 km in stage carriage mode was costlier compared to diesel buses (Transit Intelligence, 2024).

Therefore, TCO for E-buses is competitive in certain use cases already but not in all settings. Further, there are additional barriers such as high capital cost and inadequate charging infrastructure which constrain operators' ability to scale adoption of E-buses.

Figure 2.4: TCO comparison of electric and diesel bus (INR/km)



Source: WRI Procurement of Electric Buses: Insights from TCO Analysis (2021)

Figure 2.5: Cost-per-km comparison of E-bus with diesel and CNG buses

					% change			
	Cost per km (INR/km)				Without subsidy		With subsidy	
Bus type	**E bus with subsidy**	**E bus without subsidy**	**Diesel bus***	**CNG bus****	**% Diesel**	**% CNG**	**% Diesel**	**% CNG**
9m Standard floor AC	44.9	49.8	71.1	58.0	30%	14%	37%	22%
9m Standard floor non-AC	39.2	43.6	48.0	48.0	9%	9%	18%	18%
12m low floor AC	47.9	53.4	95.1	86.1	44%	38%	50%	44%
12m low floor non-AC	43.5	48.9	65.5	71.4	25%	32%	34%	39%
Average % difference of E bus cost per km compared to ICE bus					**27%**	**23%**	**35%**	**31%**

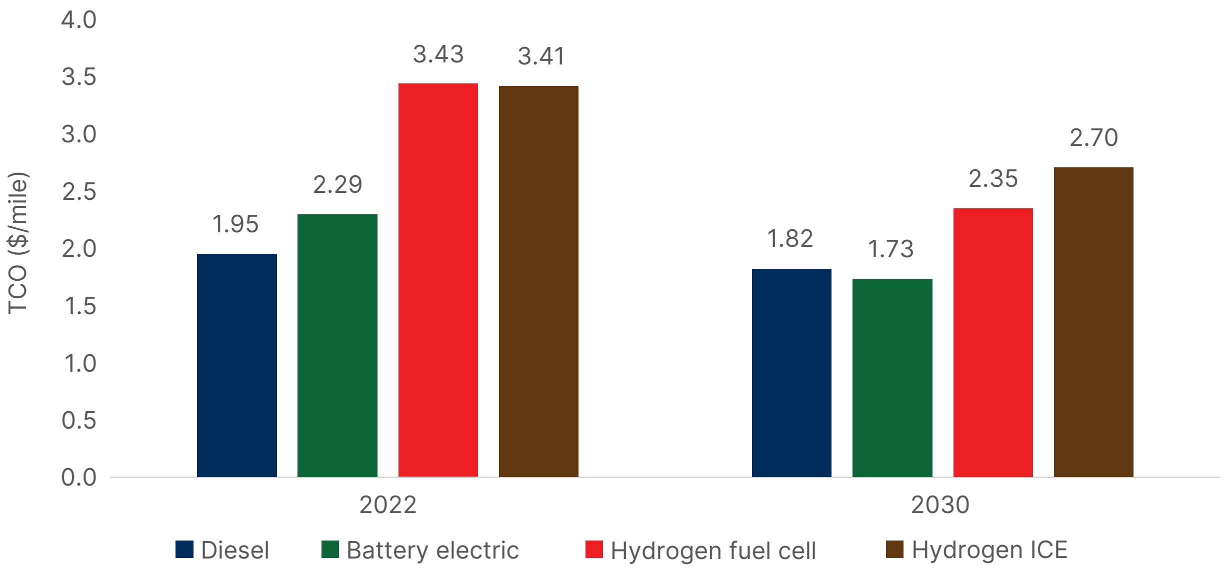
**Gross Cost Contract (GCC) rates of diesel buses in Surat, Bhubaneswar, and Mumbai*
***GCC rates of CNG buses in Delhi, Surat, etc.*
Source: TUMI (2023)

2.2.3 Comparative Analysis of Truck TCO

While E-Buses are already competitive, especially in some use cases, E-Trucks are currently more expensive on TCO basis in most cases. A recent study by ICCT for the US marked conducted a comparison for different technologies, as presented in Figure 2.6. While E-trucks were costlier by 17% compared to diesel one, hydrogen-powered trucks were 75% and 49% more expensive on TCO basis than diesel and electric trucks, respectively. However, by 2030, E-Trucks are expected to be competitive for most use cases.

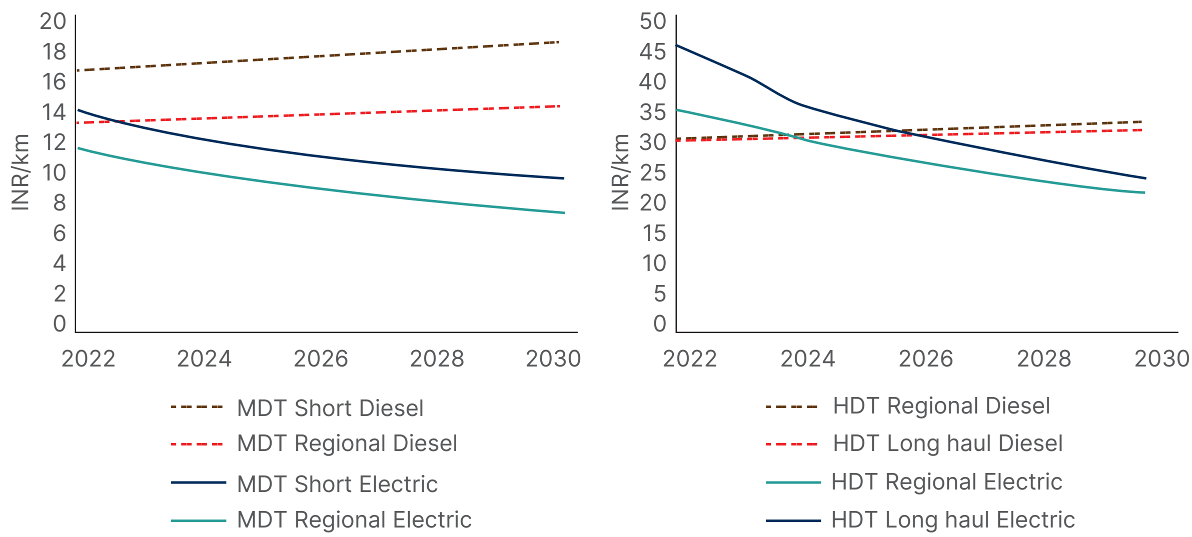
A study by NITI Aayog and RMI in 2022 conducted an economic analysis for electric Medium-Duty Trucks (MDTs) and Heavy-Duty Trucks (HDTs), as presented in Figure 2.7. While the study expected electric trucks to be competitive soon, the progress has been slow. Therefore, it is likely that some of the assumptions in the study may not have been realized. Given the recent

Figure 2.6: TCO for long haul heavy vehicles



Source: ICCT Study (Basma, et al., 2023)

Figure 2.7: TCO of MDTs and HDTs under mature production scenario



Source: NITI Aayog and RMI (2022)

ICCT analysis, albeit for the US market, TCO competitiveness for E-Trucks may take longer time and sustained policy support. Other studies such as one by Interact Analysis suggests that TCO may already be competitive but point to other structural barriers such as high initial expenditure, lack of charging infrastructure and mindset barriers (Interact Analysis, 2024). However, it is possible that some of the assumptions are not grounded in reality or that the structural barriers add implicit cost, making actual TCO to be higher than revealed. It is also the case that alternative technologies such as hydrogen fuel cell are considered strong competitors. Therefore, at this stage it is more challenging to arrive at a conclusion on the future of E-Trucks. This analysis adopts a technology agnostic view in case of the truck segment, given the technological uncertainty. Given the policy support, economic advantages and air quality challenges, the penetration of Zero Emission Trucks, including E-Trucks is expected to steadily increase.

2.3 EV Components Industry in India

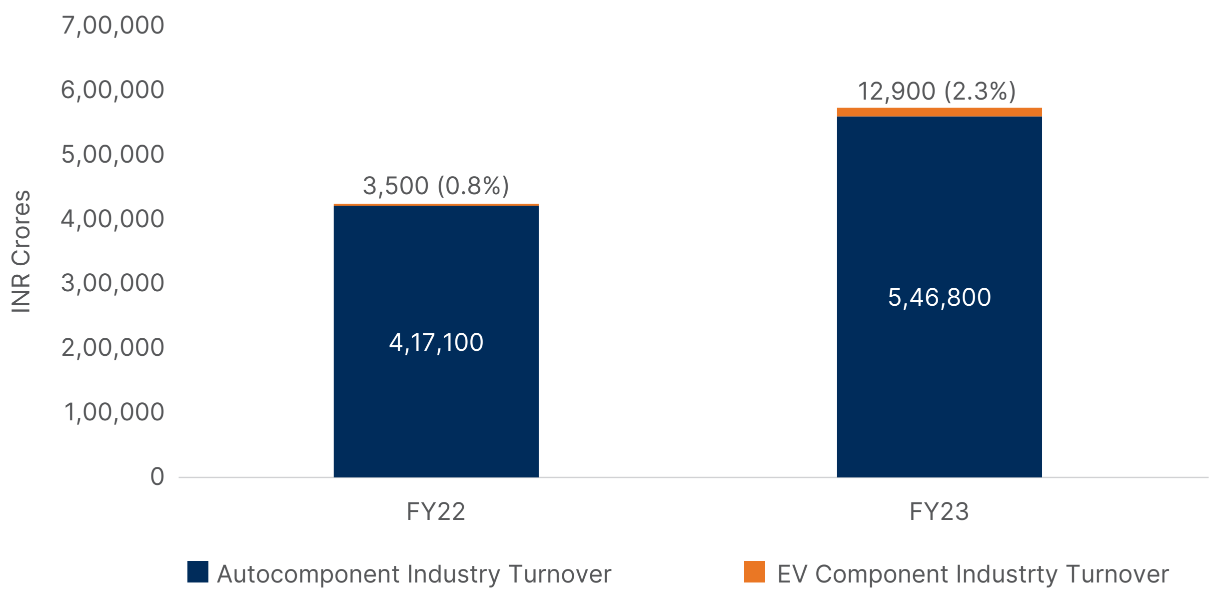
As per the Automotive Component Manufacturers Association's review, the auto components industry, including EV components, was valued at INR 5,59,700 Crores in FY23 (Figure 2.8). EV components contributed a relatively small share of 2.3% to the industry in FY 23 (ACMA, 2023). However, the share tripled over the previous year and was mainly due to increased market share of EVs.

Most EV component manufacturers cater to the domestic market, with a few established players exporting to the international market. Key players active in the international market include, Sona Comstar, Tata AutoComp Systems, Toyota Kirloskar Motor, etc.

2.4 Geographical Distribution of EV Component Manufacturers

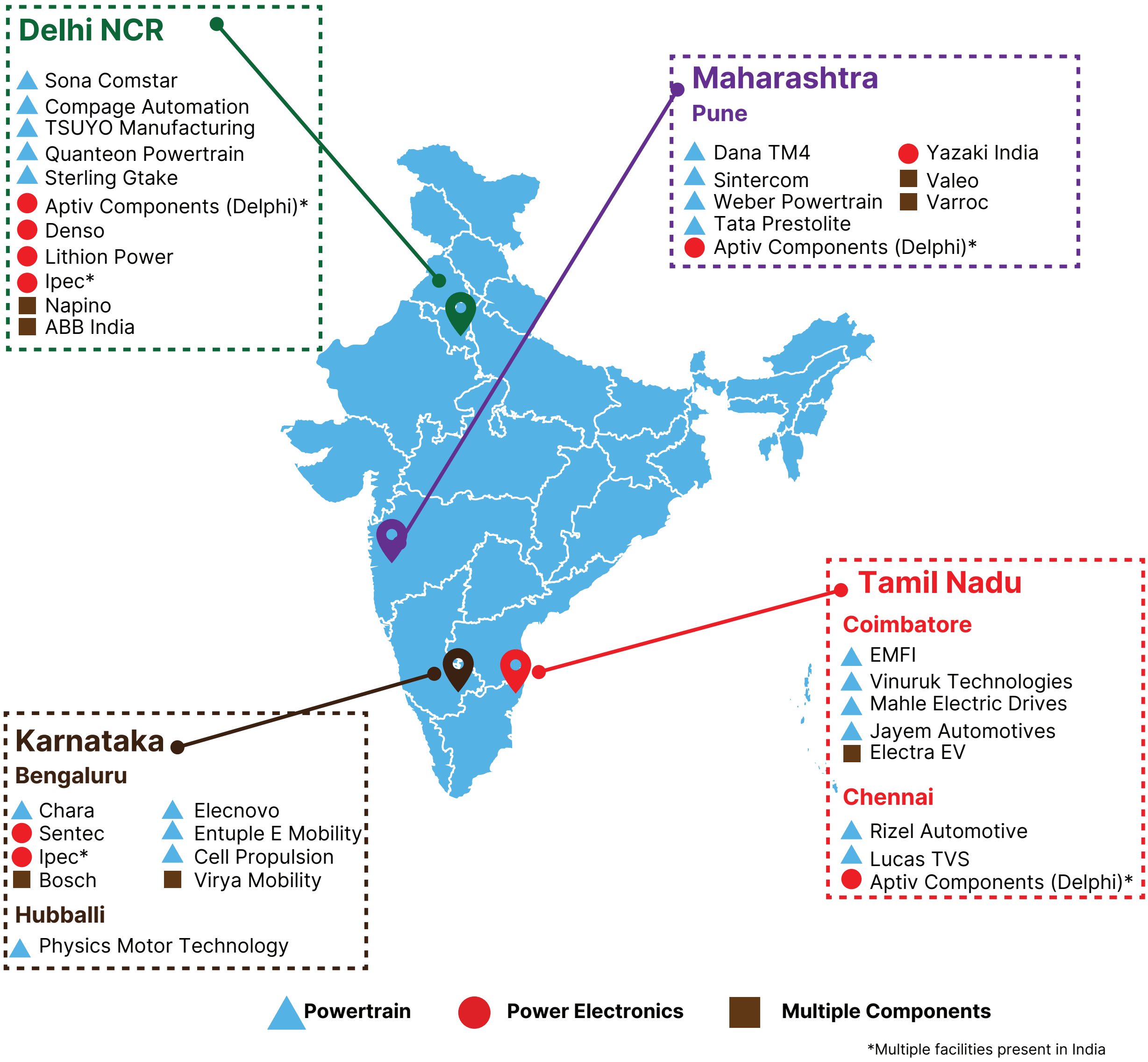
Most of the EV component manufacturers are in the three main auto clusters (Figure 2.9) – Northern (National Capital Region, encompassing Delhi and several districts surrounding it from the states of Haryana, Uttar Pradesh, and Rajasthan), Western (Pune-Chakan-Talegaon region) and Southern (Chennai–Bengaluru–Hosur cluster). EV component manufacturers comprise established Tier 1, 2, 3 suppliers and new startups.

Figure 2.8: EV component industry turnover (INR crores)



Source: ACMA (2023)

Figure 2.9: Geographical distribution of EV component manufacturers in India



Source: RTI compilation

Global EV manufacturers such as Tesla are considering setting up electric car manufacturing plants in states with existing automotive hubs such as Maharashtra, Tamil Nadu, and Gujarat. Owing to Karnataka's conducive startup ecosystem, startups are concentrated in the Bengaluru region.

2.5 Market Dynamics

There is a large set of hundred plus EV-component manufacturers in India and given the growing market and emergence of several new startups, the number is increasing steadily. There is robust activity in the startup ecosystem and as per Tracxn's database, 86 new startups in the EV component manufacturing space were established in the last few years (Tracxn, 2024).

Figure 2.10 provides a snapshot of the market dynamics and structure of the EV components industry. It is evident that few domestic players are active in large traction motors relevant for EV buses and commercial vehicles. Motor Control Units are typically bundled given the need for optimisation. DC-DC converter market is well served with multiple suppliers whereas on-board chargers are supplied by a few large players who are integrated with global semiconductor majors.

Figure 2.10: Structure of EV components market dynamics

Component	Market Dynamics	Player Size	Key Players (sample)
Traction Motors	1. Most of the players cater to 2W and 3W segments where market is crowded. Very few domestic players supply to E-buses and EV commercial vehicles given low volumes and uncertainty of demand in these segments.	Large	Dana TM4, Lucas TVS, MAHLE Electric Drives, Medha Servo Drives, Sona Comstar, Valeo, Bosch, Anand Mando, Tata Autocomp, Napino, Varroc, Shakti Pumps, Uno Minda
	2. There are large established players as well as smaller startups offering customised and low-cost solutions to 2W, 3W and E-cars. However, for E-buses and commercial vehicles, it is primarily the large, established players supplying components.	Emerging	Altigreen Propulsion Labs, Electra EV, C-EAD, Compage Automation, EMF Innovations, Entuple E-mobility, Virya Mobility, Chara, Quanteon Powertrain, Elecnovo, Rizel Automotive, Kalyani Powertrain
Motor control units	Established players provide a bundled offering with the motor. Emerging players design advanced solutions basis customised requirements from OEM clients.	Large	Sona Comstar, Dana TM4, Bosch, Lucas TVS, Tata Autocomp, Sterling Gtake, Greaves Cotton Limited
		Emerging	Chara, Electra EV, Elecnovo, Virya Mobility, Entuple E-mobilty, Kalyani Powertrain
DC-DC converter	This segment has multiple suppliers and with component standardisation, there may be less scope for emerging companies to offer differentiated benefits.	Large	Denso, Aptiv, Napino, Uno Minda, Valeo, Yazaki, Spark Minda, ABB India, Bosch, Varroc, Valeo, Borgwarner, Tata Autocomp
		Emerging	Virya Mobility, Electra EV, Star Engineers, Kalyani Powertrain
On board charger (OBC)	There is limited competition in this segment as large and established players with competence in hardware design, manufacturing and R&D capabilities have an advantage over startups. The players in this segment are well integrated with global suppliers of semiconductor devices (microcontrollers, ICs).	Large	Bosch, Tata Autocomp, Aptiv, ABB India, Napino, Varroc, Borgwarner, Valeo, Uno Minda
		Emerging	Virya Mobility, Electra EV, Star Engineers, Kalyani Powertrain

Source: RTI Analysis based on expert interviews, ACMA (2021)

2.6 EV Component Industry - Key Market Drivers

2.6.1 Push towards Localization and Indigenous Supply Chain

Government of India's vision of 'Atmanirbhar Bharat', meaning 'self-reliant India', is to create globally competitive industries in India. The objective is to reduce imports, increase livelihoods, enhance demand and accelerate growth. The policies and schemes for auto components (including EV) are aligned towards realising this vision. Over the last 8 years, several new schemes have been launched to incentivise adoption of EVs, achieve indigenisation of supply chain and expand manufacturing. Some of the key schemes with an emphasis on developing the EV ecosystem are summarised below.

The 'Make in India' initiative, launched in September 2014, facilitates investment and innovation to build best-in-class infrastructure with the aim of making India a hub for manufacturing, design, and innovation. In 2022, it focused on 27 sectors with 15 of these in the manufacturing domain and the rest in service sector (PIB, 2022). Under this initiative, the government has taken various steps to boost domestic and foreign investments in the country, like the Phased Manufacturing Programme (PMP), the Production Linked Incentive (PLI) Scheme, investments as part of the National Infrastructure Pipeline (NIP), etc.

Figure 2.11 provides a diagrammatic representation of the policy timeline for EV component manufacturing ecosystem under various schemes of Government of India over the last eight years.

a) **National Electric Mobility Mission Plan (NEMMP), 2013:** The National Electric Mobility Mission Plan (NEMMP) 2013, was a key milestone in E-mobility transition. NEMPP provided a roadmap and broad principles for the adoption of EVs. It aimed to position India as a leader in E2W and E4W market segments.

b) **FAME I (2015-2019) and FAME II (2019-2024):** Under the NEMMP, Faster Adoption and Manufacturing of (Hybrid & Electric) Vehicles (FAME-1) scheme was announced in 2015 and ended in March 2019. The second phase of the scheme (FAME II) immediately followed the first phase in April 2019 and continued till 31st March 2024. FAME III scheme is expected to be notified in FY25.

FAME I's (2015-19) main objective was to encourage market creation through demand incentives aimed at incentivising all vehicle segments including commercial vehicles and buses (PIB, 2019). Its implementation had four focus areas: demand creation, technology platform, pilot project, and charging infrastructure components. Under FAME I, DHI offered demand incentive at 60% of purchase cost or INR 1 Cr, whichever is less, for buses that achieved 35% localisation and 60% of purchase cost or INR 85 lakhs, whichever is less, for buses that achieved 15% localisation. Incentives were also provided for other segments including 2W, 3W and 4W.

FAME II scheme with a budget of INR 10,000 Crore focused extensively on providing demand incentives for public transport, shared and commercial transport, with E2W being the only exception as private owned mode of transport (Parliamentary Standing Committee, 2023). However, with the MHI exhausting funds allocated for E2W and E4W categories, the government had increased the budget for the scheme from INR 10,000 Crore to INR 11,500 Crore (PIB, 2024).

FAME II mandated localisation of components for availing incentives by following a phased manufacturing plan (PMP) and gradually increasing domestic manufacturing of EVs, assemblies and sub-assemblies; parts and sub parts, thereby increasing domestic value addition and employment. It aimed at promoting these objectives through a graded duty structure on EVs and components. The PMP timelines for EV charger components such as charging guns, power electronics were extended to Jan 2023 and Dec 2024 by MHI. Other critical components such as traction motors, controllers, Vehicle control units, DC charging inlets, on board chargers, DC-DC converters were mandated to commence indigenisation beginning 2021, in view of low local manufacturing at the time of scheme initiation.

Figure 2.11: Policy initiatives for EV component manufacturing ecosystem

2016

Automotive mission plan (2016- 2026)

Aims to increase share of local manufacturing of auto components (~4 times the value of output in 2026 from 2015 levels), increase indigenous R&D, engineering.

2017

FAME I

Demand incentive at 60% of purchase cost or INR 1 Cr, whichever is less, for E buses with 35% localization and 60% of purchase cost or INR 85 lakhs, whichever is less, for 15% localization.

2019

FAME II

Phased Manufacturing Plan

FAME II eligibility mandates localization of drivetrain components as per the Phased Manufacturing Program. Powertrain components were scheduled to attract BCD of 15% from Apr'21 onwards.

2021

Production Linked incentive scheme for automobile & auto components

Incentives provided to EV component manufacturers linked to domestic sales value subject to meeting eligibility criteria & achievement of min 50% DVA

2023

Standard operating procedure for certification of Domestic value addition

2024

Scheme to promote manufacturing of Electric cars in India

Approved applicants will be allowed to set up manufacturing facilities with min investment of USD 500 M. Applicant shall be allowed to import CBU at reduced customs duty of 15% subject to conditions

EMPS

Demand incentives for locally manufactured E2Ws and E3Ws

FAME II reported utilisation of about 90% of the funds, by the scheme's deadline on 31st March 2024, spending Rs 10,253 Crore out of the total Rs 11,500 Crore benefitting over 1.5 Million vehicles.

Source: RTI Analysis

By the scheme's deadline on 31st March 2024, FAME II reported utilisation of about 90% of the funds, spending Rs 10,253 Crore out of the total Rs 11,500 Crore allocated. Among the categories, E3W was able to utilise 100% of funds allocated, followed by bus category at 94%, and E2W at 90% utilisation of their respective allocations. The lowest fund utilisation of 64% was for E4Ws (MHI, 2024) (Business Standard, 2024). With 68 OEMs and 11 EV manufacturers approved under the scheme, and over 1.5 Million beneficiary vehicles, FAME II helped to increase the overall EV penetration to 6.8% by FY24, against 5.3% in FY23.

c) **Production Linked Incentive (PLI) Scheme for Automobiles and Auto Components, 2021:** In a bid to boost domestic manufacturing within the EV value chain, the government introduced two Production Linked Incentive (PLI) schemes for automobile sector. One focused on supporting setting up competitive Advanced Chemistry Cell (ACC) battery manufacturing units with a budget of INR 18,100 Crore. The other is for automobiles and auto components. The PLI battery scheme is not discussed since it is beyond the scope of this study.

The PLI scheme for automobiles and auto components aims to overcome cost disabilities, create economies of scale, and build a robust supply chain in areas of Advanced Automotive Technology (AAT) products. It also aims to generate employment and enable the auto industry to move up the value chain.

The PLI scheme presents several opportunities for the automobile industry, including EV component manufacturers as shown in Figure 2.12.

The auto PLI scheme has two components with total budgetary outlay of INR 25, 938 Crores. There is no segregation for vehicles and auto components in the scheme.

i. Champion OEM Incentive scheme

ii. Champion Component Incentive scheme

Champion OEM Scheme aims to provide incentives linked to the determined sales value to eligible applicants fulfilling the base and add-on eligibility criteria. OEMs of AAT vehicles, including EVs and hydrogen fuel cell vehicles are eligible and thus far 18 have been approved (MHI, 2024).

Champion Component Incentive Scheme is a sales-value linked scheme that incentivises EV component manufacturers. Almost all critical EV components including, traction motors, motor controllers, Vehicle control unit (VCU), HV (High Voltage) harness, connectors, DC-to-DC converters, OBC, and rare earth magnets used for motors, are eligible for incentives under this scheme. Completely knocked down (CKD) and semi-knocked down (SKD) kits and vehicle aggregates in various segments, manufactured in India from 1 April 2022 onwards, for a period of five consecutive years are also eligible. The scheme was amended in December 2023, and extended to FY28.

Thus far, three auto companies viz. Tata Motors, Mahindra & Mahindra, and Ola Electric have

Figure 2.12: Production Linked Incentive (PLI) opportunities for EV component manufacturers

PLI opportunities for EV component manufacturers
Import substitution and increase in exports – Companies can evaluate technology transfer and manufacturing to reduce imports. It's an opportunity to expand scale and become low-cost export hubs.
Expansion to new markets – Potential to increase FDI inflow from global companies into eligible products.
New product introduction – Players from other allied and non-allied sectors have an opportunity to foray into component manufacturing.
Vertical integration – Auto OEMs can enter component manufacturing.

Source: Adapted from Ernst & Young (2021) been able to obtain the Domestic Value Addition (DVA) certification (Economic Times, 2024), out of eighty-five applicants (Live Mint, 2024). DVA certification has been received for 22 variants of AAT products. DVA refers to the percentage of manufacturing activity undertaken locally for a particular component[1]. A key criterion to avail incentives is the achievement of a minimum DVA of 50 per cent for the product for which the incentive is being claimed.

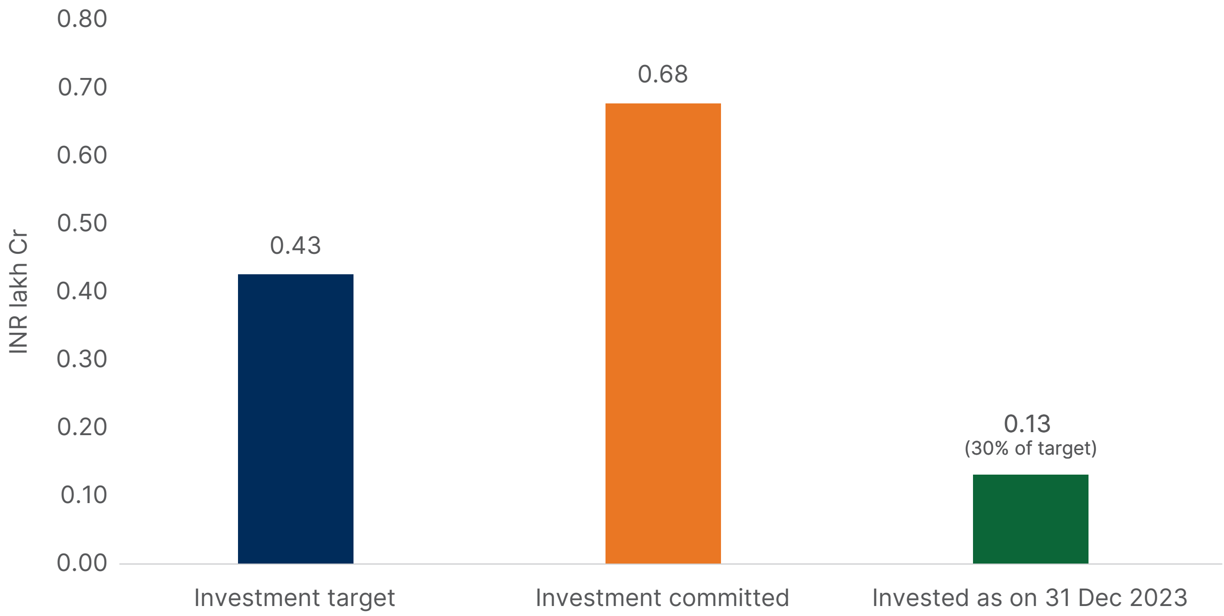
Under the Champion Component Scheme, Sona Comstar was the first company to receive DVA certification in February 2024 (Economic Times, 2024). By July 2024, the company had secured four DVA certifications for various traction motor configurations. Toyota Kirloskar has also received certifications for two variants of trans-axle. Many other product approvals are under process for DVA certification by automotive component suppliers (Live Mint, 2024). Component manufacturers are in the process of having their manufacturing facilities and plants audited by testing agencies and completing compliance with the appraisal process.

The key objectives of the PLI scheme are to stimulate investment and generate employment. As per the MHI, the PLI auto scheme appears to be enabling progress on the stated objectives. Investment commitment of INR 67,600 Cr, exceeding the proposed target of INR 42,500 Cr (PIB, 2024) have been made. Further, about 30% of the targeted investment has been invested by 31st December 2023. In the terms of employment generation, 28,515 persons have been employed, about 20% of the employment proposed by companies (Economic Times, 2024). Figures 2.13 and 2.14 summarise the progress achieved on investments and employment under the PLI auto schemes.

Based on the implementation experience, the PLI scheme has undergone two amendments since its notification (Figure 2.15). However, some concerns persist regarding the administrative and substantive aspects of the scheme. These are further discussed in Chapter 5 of this report.

d) **India Semiconductor Mission, 2021:** Semiconductors have a significant role in increasing efficiency, impacting overall performance and improving the range of EVs. Accordingly, the Government of India introduced multiple initiatives under the flagship Semicon India Programme, launched with an outlay of INR 76,000 Crore in December 2021 (PIB, 2023). The programme aims to build a

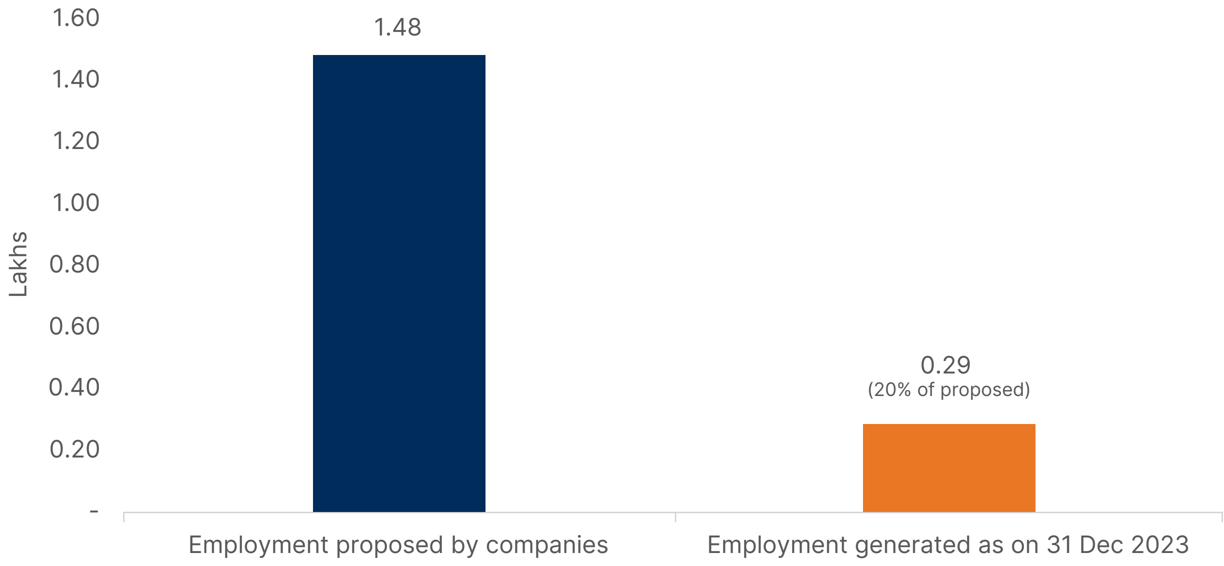
Figure 2.13: Production Linked Incentive (PLI) auto and components scheme investments (INR lakh Cr)



Source: RTI analysis based on PIB (2024) includes both champion-OEM automobile and component-champion scheme

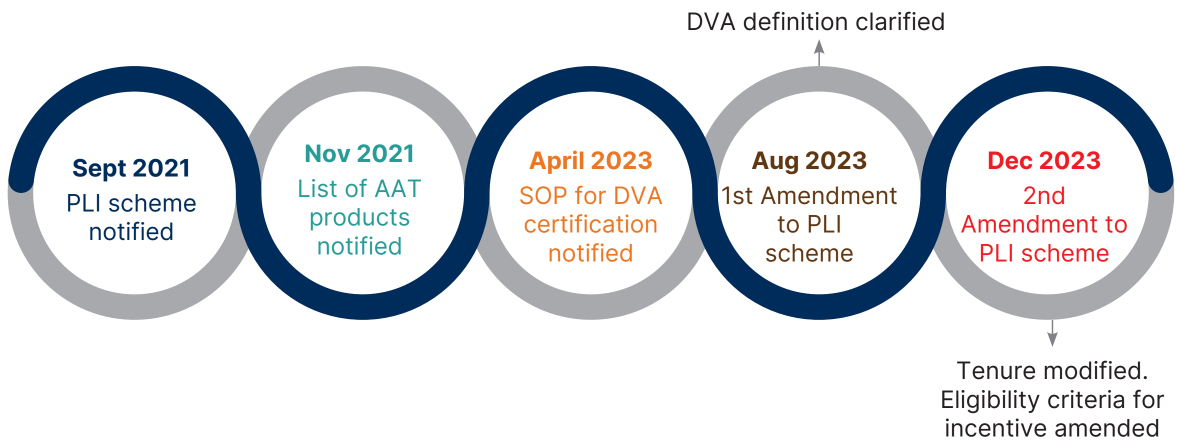
[1] *% DVA = [{Adjusted Ex factory price of product-Adjusted import content}/ Adjusted ex-factory price of product] *100. Adjusted ex-factory price is the price at factory gate excluding exempted imports.*

Figure 2.14: Employment generation under PLI auto and component schemes (in lakhs)



Source: RTI analysis based on PIB (2024)

Figure 2.15 : PLI scheme evolution



Source: PLI auto portal, GoI

comprehensive semiconductor manufacturing ecosystem in the country. The schemes include setting up of wafer fabrication facilities, development of compound semiconductors, assembly, and testing units etc.

Various schemes under the Semicon Programme provide fiscal support, wherein the central government offers upto 50 percent of the project cost subject to different ceilings of cost and time —with some additional fiscal support provided by the state governments (PIB, 2022). Incentives are provided to companies for establishing semiconductor foundries, outsourced assemblies, and test (OSAT) facilities or display fabs. The funds are made available on 'pari-passu' basis where funds are made available immediately, upfront to the companies (PIB, 2022).

As a result of the Semicon programme, three major firms, including the Tata Group, have announced USD 15 Billion of investments in chip manufacturing in India in 2024. The first Made in India chip is expected to be rolled out by 2026 (Economic Times, 2024).

e) **E-Vehicle policy to promote India as a manufacturing destination (Scheme to Promote Manufacturing of Electric Passenger Cars in India):** This scheme aims to attract investments from global EV manufacturers and promote India as a manufacturing destination for EVs. The scheme is particularly intended to facilitate entry of global OEMs to establish manufacturing facilities in the country.

The scheme allows eligible applicants to set up manufacturing facilities for electric cars in India subject to a minimum investment commitment of INR 4,150 Crores (USD 500 M). There is no cap on the maximum investment. The investment shall include plant, machinery, charging infrastructure, equipment etc. (PIB, 2024). Cost of land is not considered for meeting the threshold criteria of investment.

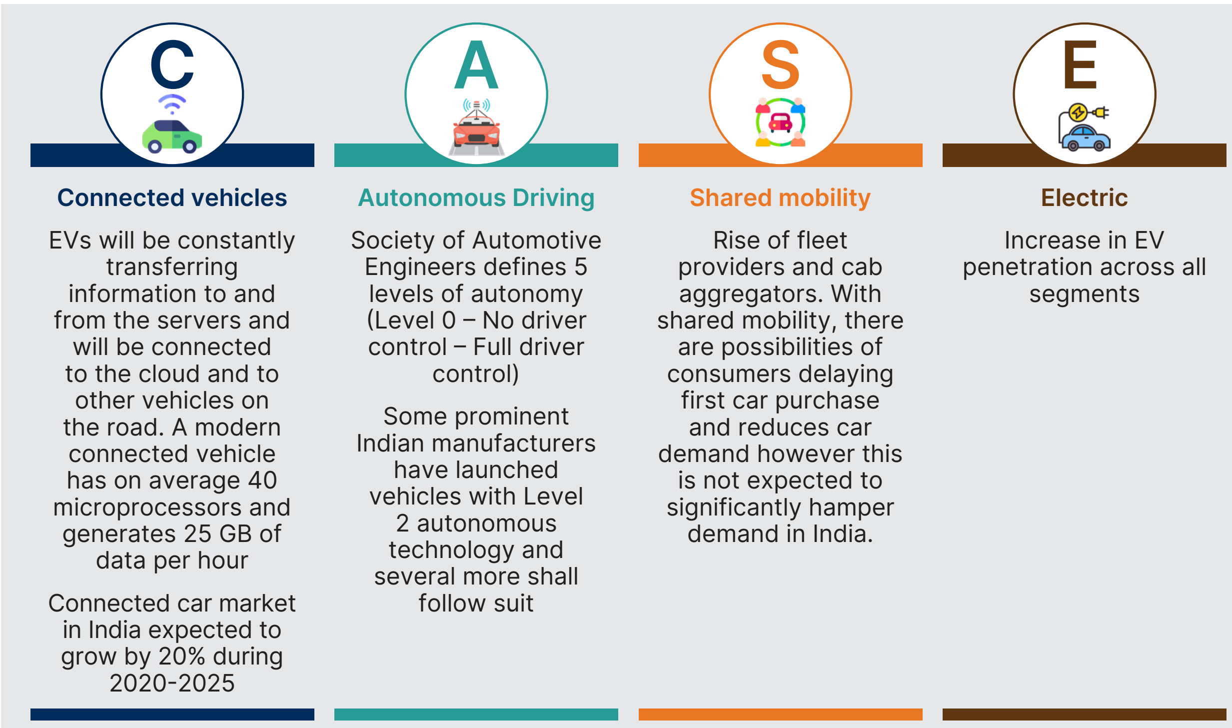
The manufacturing facilities will have to be made operational within three years. It also specifies a minimum DVA of 25% to be achieved within 3 years and 50% to be achieved within 5 years. Approved applicants are allowed to import CBUs at a reduced customs duty of 15% (PIB, 2024).

f) **Electric Mobility Promotion Scheme (EMPS), 2024:** EMPS is a demand side incentive scheme for E2Ws and E3Ws for a period of four months from April 01, 2024 to July 31, 2024. The budgetary outlay for this scheme is INR 500 Crores. Demand incentive of INR 5000/kWh for E2Ws and E3Ws will be provided, capped at 15% of the ex-factory price (PIB, 2024). To qualify for these incentives, the EVs should be manufactured in India and have local manufacturing and assembly of parts as specified in the scheme.

2.6.2 Connected, Autonomous, Shared, and Electric (CASE)

The Indian automobile and component market is expected to evolve in line with the global trend of 'CASE' i.e., Connected, Autonomous, Shared, and Electric (Figure 2.16). CASE, a megatrend in automotive technology is expected to increase the demand for components that enable autonomous

Figure 2.16: CASE characteristics



Source: RTI analysis; Mordor Intelligence (2023) driving including sensors, semiconductors, and sophsiticated software.

A connected vehicle relies heavily on sensors, like cameras, LIDAR (Light Detection and Ranging), and RADAR (Radio Detection and Ranging). The hardware to transmit the inputs from these sensors is provided by semiconductors. Data gathered by various sensors is procesed by semiconductors to arrive at usable information for real-time driving decisions. Sophisticated machine learning and mapping software further improve operation adding to the reliability of driving decisions. The percentage of connected cars[2] in the PV segment increased from 35% in 2021 to 46% in 2022 (JATO Dynamics, 2023). While, the number of EV connected cars were small, moving forward this is expected to increase significantly, driving up demand for power electronics.

In terms of semiconductor content, according to an analysis by the P3 Consulting Group, an EV has twice the number of semiconductors as compared to an ICE vehicle. Most semiconductors are in the powertrain, especially the inverter. Any disruption in semiconductor supply chain thus affects EV production more than ICE vehicles (Elective, 2022).

A US Government estimate (Figure 2.17) suggests that the average semiconductor content per car could increase several times i.e., from USD 160 (Level 2) to USD 630 (Level 3) to USD 970 (for Levels 4 and 5) with a total of up to 3,500 semiconductors per vehicle (USITC, 2019).

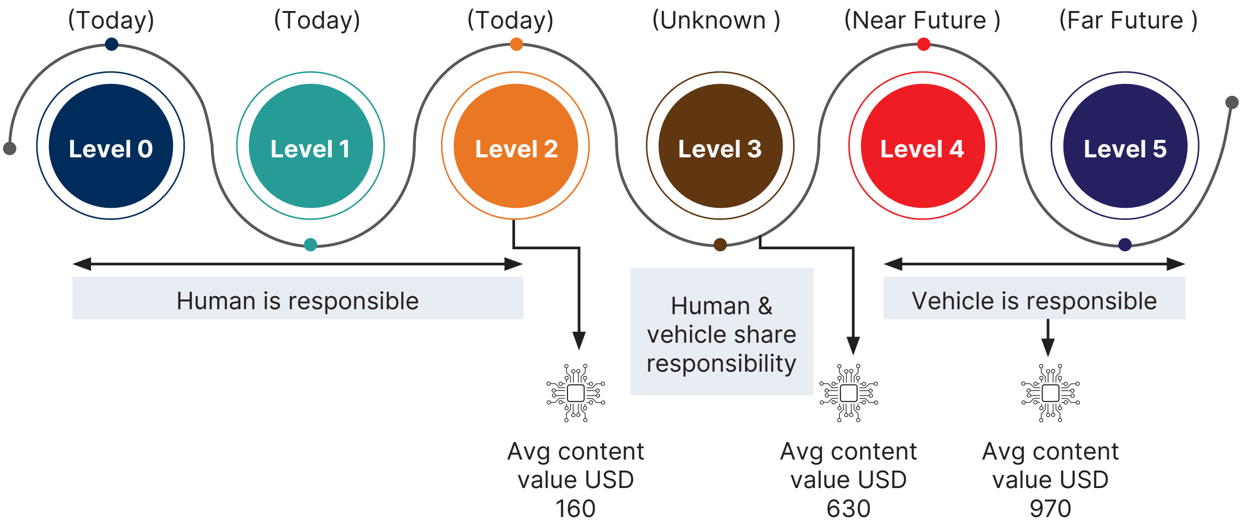
The demand for automotive semiconductors in India is expected to witness the highest growth (29%) among various end use segments and expected to reach USD 3.8 Billion by 2025 (TechSci Research, n.d.).

It is expected that the global revenues from autonomous driving will reach USD 300- 400 Billion by 2035 (McKinsey & Co., 2023). It presents an opportunity for India particularly in segments such as chip manufacturing, specialised software, batteries etc.

2.6.3 New Modes of Engagement with Suppliers and Changing Industry Order

With different type of components and technologies driving EVs, new engagement and business models are emerging with a higher degree of collaboration over the traditional approach. Original Design Manufacturers (ODM), is one such example. ODMs focus mainly on design and development of solutions (Figure 2.18). They own the IP of the product, but may not be directly involved with branding, distribution, and marketing of products.

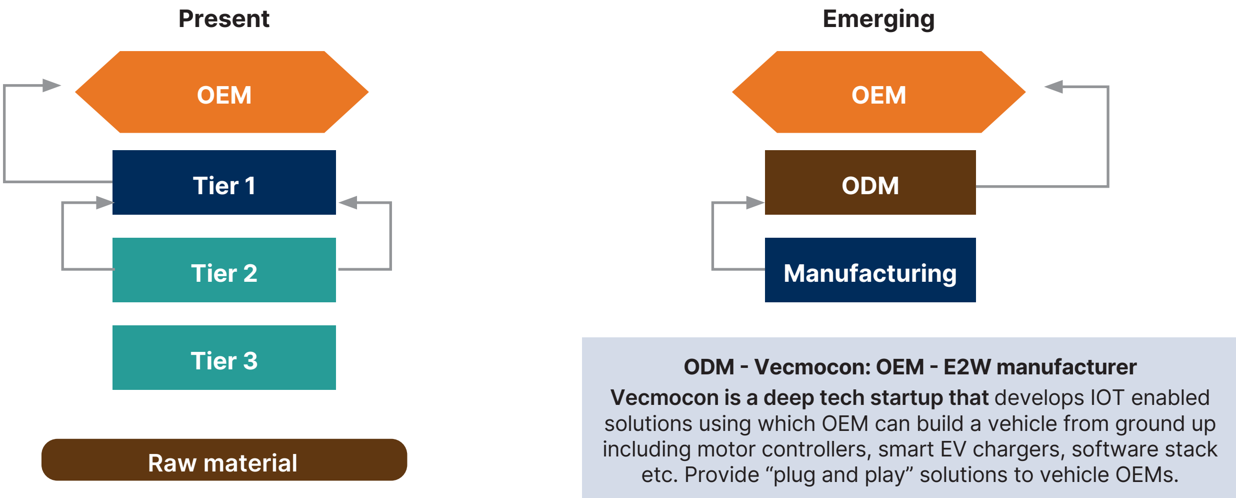
Figure 2.17: Rise in semiconductor content with levels of autonomous driving



Source: Adapted from Indian Automotive Sectorial System of Innovation, UNIDO and DST, March (2023)

[2] *Connected car refers to PV that has embedded software that enable the user to communicate with external gadgets like smartphones or smart devices (at home), or other vehicles via wireless communication like Bluetooth, wi-fi*

Figure 2.18: Emergence of original design manufacturer in the EV value chain



Source: RTI representation; Blume (2023)

Figure 2.19: Traction motors designed for Indian market

Traction motors designed for Indian 2Ws

Israel-based EVR Motors is setting up a wholly-owned subsidiary, I.EvR Motors Pvt Ltd, in Manesar to manufacture electric motor coils- its patented technology for its partners in India and abroad (EVR Motors, 2024). EVR's electric motors are 30%-50% lighter and smaller, cost less and can be tailored to user requirements for two- and three-wheelers (EV Tech News, 2023). In 2022-23, EVR was granted ten patents for its new technology, and more patents are expected (Automotive World, 2023).

Source: EVR Motors (2024); EV Tech News (2024); Automotive World (2023)

Typically, component suppliers design solutions as per the specifications of the client, while ODMs have pre- designed products and solutions, which can be sold under the manufacturer's brand name.

These models are enabling emergence of nimble startups which specialise in developing differentiated components and software development. For instance, C Electric develops EV powertrains, with an in-house motor control algorithm that caters to the needs of Indian roads and climatic conditions.

2.6.4 Product Development for Indian Climatic Conditions

The need for EVs suited for India's unique terrain and tendency to overload vehicles is prompting several manufacturers to design and manufacture products locally and opt for locally developed components.

Established component suppliers are starting to invest in research and product development to make quality products (Figure 2.19).

These market drivers have led to an increase in investments by OEMs as well as component manufacturers.

2.7 Investments in EV Sector

Investments in e-mobility are growing driven by EV sales and entry of new players. The EV industry attracted Foreign Direct Investment (FDI) inflow of nearly USD 6 Billion in 2021 and it is projected to rise to USD 20 Billion by 2030 (Government of India, 2022).

2.7.1 Investment Commitments by EV OEMs

A total investment amount of USD 10.5 Billion has been committed by the OEMs towards EVs. A few large players (Tata, Mahindra, MG Motor, and Hyundai) are responsible for over 60% of the total investments. Further, most of the investments are being made by the approved PLI champion OEMs with Tamil Nadu, Maharashtra and Karnataka being the preferred states for investments. Figure 2.20 provides an overview of investments announced in the recent years by OEMs. These investments will drive demand and investments in component manufacturing.

The largest commitment has been made by Hyundai Motors, i.e., to invest INR 20,000 Crores over the next ten years for manufacturing EVs and for setting up a battery pack assembly unit. Tata Motors has announced an investment of INR 18,000 Crores in its electric vehicle division until FY30. Mahindra & Mahindra Ltd. is planning to invest INR 12,000 crore in its electric vehicle unit, Mahindra Electric Automobile, over a period of 3 years till FY27. There are strategic investments planned in E-bus and E-mini-trucks manufacturing by a few players. For instance, Pinnacle mobility solutions is planning to set up E-bus and E-trucks manufacturing facilities in Madhya Pradesh auto cluster. Ashok Leyland has also announced investments for E-buses and E-trucks manufacturing. Murugappa Group plans to invest INR 3,000 crores to launch electric small commercial vehicles through TI Clean Mobility.

Among other investments in the sector, the BMW Group and Tata Technologies announced a joint venture partnership in April 2024. The partnership will set up an automotive software and IT development hub (spread across the cities of Pune, Chennai, and Bengaluru) to deliver automotive software solutions for BMW's premium vehicles and digital transformation solutions for its business (BMW Group, 2024) (Figure 2.20).

2.7.2 Investment Commitments by Component Manufacturers

The established Tier 1 component manufacturers have traditionally been focused on ICE components but have started to invest in EV components. Investments are being made for establishment and expansion of manufacturing facilities and to some extent R&D. Figure 2.21 provides an overview of the recent investments announced by EV component manufacturers in India. Around USD 3 Billion has been committed, mostly by approved component champions under the PLI scheme out of which many are planned for the state of Maharashtra.

The largest commitment is by JSW group, which is investing across the EV value chain. It plans to set up an EV and EV battery manufacturing plant along with an EV component manufacturing complex with copper and lithium smelters. Out of the total investment of INR 40,000 Cr, about 37% (INR 15,000 Cr) are planned to be invested towards EV component manufacturing. Players like TATA Autocomp, Varroc, Uno Minda etc. are investing in powertrain facility expansion. Bosch and Aptiv are investing in advanced automotive technologies (Figure 2.21).

EV components manufacturing is a capital-intensive business, and it is noted that established players (primarily those approved under the PLI champion component scheme) are planning the largest investments. Micro, Small, and Medium Enterprises (MSMEs) and startups have budget limitations which is a challenge, particularly for investments in R&D. This is because the outcomes associated with R&D are uncertain and may take time and are therefore considered risky. During one-to-one meetings with the RTI team, some of the industry stakeholders expressed interest in collaborative R&D investments.

2.7.3 Private Equity and Venture Capital Funding

As startups are dominant in the India's EV ecosystem, private equity (PE) and venture capital (VC) funding has been a significant

Figure 2.20: Investments by EV OEMs (INR Cr)

Firm name	Year	Investment (INR Cr)	State	PLI Champion OEMs	Objective
TATA Motors Limited	2024	18,000 (till FY30)	Multiple	Yes	Electric Vehicle Division
Mahindra & Mahindra Limited	2024	12,000	Multiple	Yes	Expansion of manufacturing facilities to launch 16 electric vehicles (EVs) by 2027 across SUV and light commercial vehicle categories
MG Motor and JSW Group	2024	5,000	Gujarat	No	Set up manufacturing plant for new energy vehicle segment
TVS Motor	2024	5,000		Yes	Design, development, and deployment of future technologies, products, and digital capabilities
VinFast	2024	4,000	Tamil Nadu	No	Set up integrated EV manufacturing unit
Maruti Suzuki India Limited	2024	3,200 additional 35,000 Cr	Gujarat	Yes	Investment of INR 3,200 Crore for a new production line at its existing facility in Gujarat; expected to start operation from FY2026-27 to produce 2.5 lakh additional units a year. Plans for an additional investment of INR 35,000 Crore for a second plant in Gujarat; the plan to begin operations from FY2028-29
TI Clean Mobility- Tube Investments of India	2024	3,000		No	Establish platform for electric small Commercial Vehicles.
Ather Energy	2024	1000	Maharashtra	No	Third manufacturing plant in Aurangabad, with a capacity of 1 million two-wheelers per annum.
Volvo Eicher Commercial Vehicle	2024	1,000		Yes	Developing alternative fuel technologies for new-age CVs.
NexGen Energia	2024	1,000	J&K	No	Set up EV manufacturing facility
Hyundai Motor India Limited	2023	20,000 (next 10 years)	Tamil Nadu	Yes	Introduce six new battery electric vehicles (BEVs) in the Indian market by 2028, establish battery pack assembly unit with an annual capacity of 1,78,000 units, expand total production volumes to 8,50,000 units per year.
Ashok Leyland Limited	2023-24	2200	Tamil Nadu, UP	Yes	EV arm Switch Mobility to utilise it for capital expenditure, R&D, and meeting operational requirements in the UK and India. Also, investing to establish a bus manufacturing facility in Uttar Pradesh.
Kia India Private Limited	2023	2000 (next 4 years)	Andhra Pradesh	Yes	Manufacturing and infrastructure development for EVs.
Nexzu Mobility	2023	5000	Gujarat	No	Smart EV Park
Pinnacle Mobility Solutions Private Limited	2023	2000 (over 5 years)	Madhya Pradesh	Yes	Set up a 5,000-unit E-bus manufacturing plant (9m and 12 m) and electric mini trucks (1-2T) including R&D, plant equipment and set up.
JBM	2023	500	Haryana	No	Capacity enhancement and product and technology R&D
Hero MotoCorp Limited	2022	420	Karnataka	Yes	Collaborations with Ather Energy in various spheres such as charging infrastructure, technology and sourcing.
Greaves Electric Mobility Private Limited	2022	1160	Karnataka	No	Develop new products, associated technologies, brand awareness, aiming to transform the company into a leading global EV manufacturer.
Bajaj Auto Limited	2022	1000	Maharashtra	Yes	Establishment of a new EV unit in Pune.
Total committed Investments ~ INR 87,480 Cr (USD 10.5 Billion)					

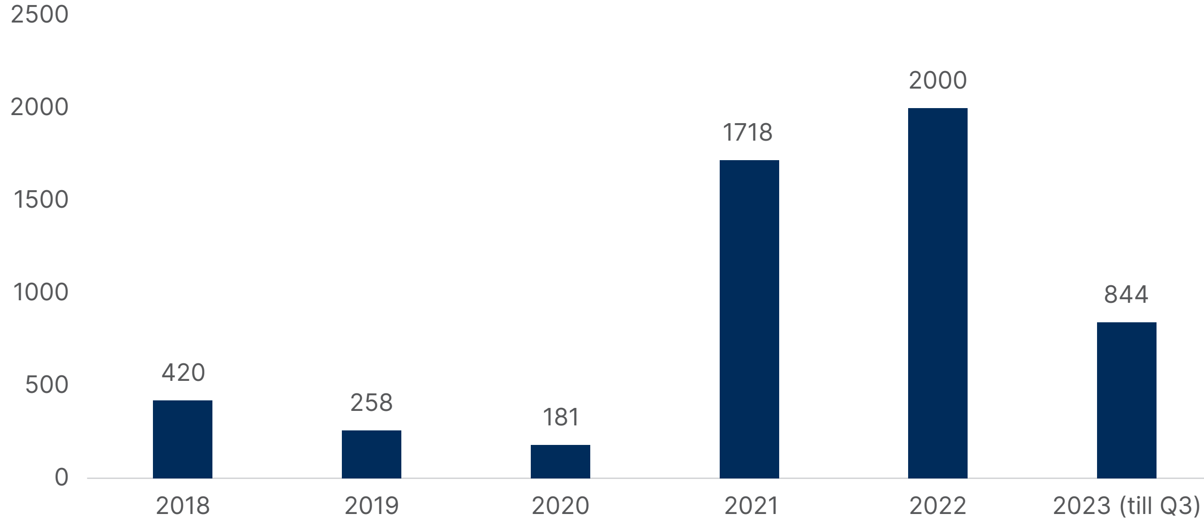
Source: RTI compilation based on company websites, annual reports and articles in the Press

Figure 2.21: Investment commitments by EV component manufacturers

Firm name	Year	Component segment	Investment (INR Cr)	State	PLI approved component champion	Objective
JSW Group	2024	Powertrain and power electronics	14, 800 (~37% of total committed investment towards EV components)	Odisha	No	To build an integrated OEM and EV component manufacturing plant including battery, powertrain, lithium refinery, copper smelting etc.
Bharat Forge	2024	Powertrain	500	Maharashtra	Yes	For funding capex for EV component manufacturing plants.
Erisha E-mobility Pvt Ltd	2023-24	Powertrain	4,500	UP, Uttarakhand, Gujarat	No	Establishing a first-of-its-kind EV Park, which will provide a platform for EV manufacturing, ancillary units set up, technology providers, and researchers to collaborate.
Anand Mando	2024	Powertrain	987	Tamil Nadu	Yes	Expand Production capabilities
Sona Comstar	2023	Powertrain	1,200 (next 3 years)	Haryana	Yes	Expand Production capabilities
Wardwizard Innovations & Mobility Ltd.	2023	Powertrain	2,000	Gujarat	No	Development of an EV Ancillary Cluster by 2024 which will provide land, manpower, and essential facilities to manufacturing partners for supplying components to Wardwizard and other OEMs.
Aptiv Components India Pvt. Ltd.	2023	-	115	Karnataka	Yes	Development of a technical centre campus in Bengaluru- the site serves as a centre of excellence for ADAS platforms and technologies and digital cockpit solutions.
Valeo India	2023	Power electronics	525 (~35% of total committed investment)	Gujarat and Maharashtra	Yes	Expansion of facilities for EVs (Pune) and setting up a second manufacturing line (Gujarat).
Omega Seiki	2023	Powertrain	800	Maharashtra (battery), Haryana (Powertrain)	No	Building two facilities to manufacture batteries and powertrains.
Uno Minda	2023	Powertrain	300	Haryana	Yes	Setting up two manufacturing plants for EV components.
Varroc	2022	Powertrain	600	Maharashtra (Pune)	Yes	Capacity expansion for EV components.
Tata Autocomp Systems	2022	Powertrain	1,250 (~50% of total committed investment)		Yes	For manufacturing and localisation of powertrains.
Bosch	2022	Power electronics	200		Yes	Towards advanced automotive technologies and digital mobility space.
Weber Drivetrain Pvt. Ltd.	2022	Powertrain	35	Maharashtra	No	Establishing a manufacturing unit under the 'Make in India' initiative.
Total committed investments ~ INR 26,812 Cr (USD 3.25 billion)						

Source: RTI compilation based on annual reports, company websites and articles in the press

Figure 2.22: PE/VC funding in the E-mobility sector (USD Million)



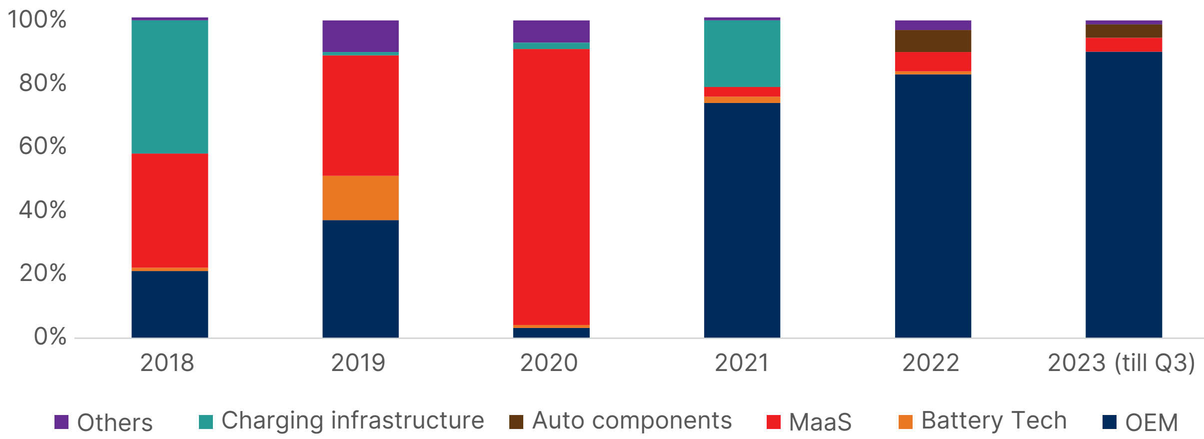
Source: Invest India and SAREP (2023); Bain (2023); Grant Thornton (2023)

contributor of this growth. The share of funding for e mobility in India has grown from about 6% of total VC funding in 2022 to 22% in 2023 (Ostara Advisors, 2024).

The size of PE/VC funding for EV has increased by 47% CAGR between 2018-2022, to reach USD 2 Billion in 2022 (Figure 2.22). A part of the funding is for CAPEX by OEMs to build production capacity, undertake operations, and for expansion plans. OEMs in 2W, 3W and 4W accounted for over 80% of the deal value in 2022 (Bain, 2023) (Figure 2.24). Further, investments have been concentrated amongst incumbents and a handful of startups. For instance, Tata Passenger Electric Mobility and Mahindra EV accounted for about 37% of the total EV deal value of USD 2 Billion. Other segments that attracted significant funding are charging infrastructure and mobility as a service.

Since 2022, there has been an increasing interest in EV component manufacturing. PE/VC funding for EVs including component manufacturing (excluding batteries) reached 7% in 2022 from an almost negligible share in the previous years (Figure 2.23). Some of the large deals in the EV category in 2022 are presented in Figure 2.24.

Figure 2.23: Share (%) break-up of PE PE/VC funding in the E-mobility sector



Source: Invest India and SAREP (2023); Bain (2023); Grant Thornton (2023)

Figure 2.24: Key deals in EV OEMs and EV components industry in 2022

Segment	Firm name	Lead investor	Deal Value
EV OEMs			
2W and 3W	Ampere Vehicles	ALJ	USD 220 M
2W and 3W	Ola Electric	Tekne Capital Management	USD 200 M
2W and 3W	Ather Energy	NIIF, Caladium Investments	USD 178 M
2W and 3W	Euler motors	GIC	USD 60 M
2W and 3W	Altigreen Propulsion	Sixth Sense Ventures	USD 40 M
2W and 3W	Batt:RE	Shell	USD 26 M
4W	Tata Passenger Electric Mobility	Rise Fund	USD 496 M
4W	Mahindra EV	British International Investment	USD 250 M
4W	Evage Ventures	RedBlue Capital	USD 28 M
EV components			
Multiple	Vecomocon Technologies	Neev Fund	USD 26 M
Multiple	Log9 Materials	Tiger Global, Orios Venture Partners, Blume	USD 25 M
Multiple	Electrodrive Powertrain Solutions Pvt. Ltd.	GEF Capital (South Asia Growth Fund II)	USD 25 M

Source: Bain (2023), RTI compilation from annual reports, company websites and press articles

2.7.4 Nifty EV & New Age Automotive index

Given the vibrancy of the automobile sector and large investments planned in EV ecosystem, the NSE Indices Limited launched a new thematic index- Nifty EVs New Age Automotive Index on May 30, 2024. The index will track the performance of companies which form a part of the EV ecosystem or are involved in the development of new age automotive vehicles or related technology.

As evident from Figure 2.25, the composition of the index is weighed towards automobile and auto component companies followed by IT companies. It is considered representative of the evolving EV industry and expected to enable the sector to raise capital needed for planned investments.

Figure 2.25: Composition of NIFTY EV & new age automotive index

Sector	Weight(%)
Automobile and Auto Components	69.01
Information Technology	13.48
Chemicals	8.08
Capital Goods	5.07
Oil, Gas & Consumable Fuels	4.29
Consumer Services	0.07

Source: NSE

3. EV SALES SCENARIOS

Source: MS stock

The best way to predict the future is to invent it.

Alan kay

3.1 Literature Review

This chapter presents multiple scenarios of potential EV sales and penetration levels for two periods - medium term (2024 to 2030) and long term (2030 to 2047). As EVs have become mainstream in the recent past, paucity of historical data is a significant challenge for developing the outlook. These scenarios present a spectrum of probabilities with outcomes dependent on evolution of policy, regulation, technology, and market.

As part of the literature review, various models and forecasts were reviewed. The first section presents some of the key highlights, followed by results from modelling exercise.

3.1.1 Consumer Choice Model

A consumer choice model is a framework used to understand and predict how consumers make decisions amongst different options. These models work by simulating the decision-making process of consumers. This is achieved by:

1. Identifying the key attributes of the products or services being considered (for example TCO, resale value etc. in case of vehicles).
2. Collecting data on how consumers value these attributes, often through surveys or conjoint analysis. This helps determine the relative importance of each of the attributes to consumers.
3. Model development using statistical techniques (e.g., Multinomial Logit Model) to build a mathematical representation of how consumers choose based on the identified attributes and their values.
4. Scenario simulation by providing different inputs, say for different pricing strategies, new product features etc. to predict how consumers are likely to respond in terms of their choices.

Such models are preferred when large data sets exist on consumer preferences and choices. When data is limited, as in the case of EVs, information must be collated through surveys (Coffman, et al., 2015).

A recent World Bank study (World Bank, 2022) focused on three segments (2W, 3W and 4W) of electric vehicles to develop a Consumer Choice Model. It estimates annual vehicle sales using population and economic activity (city GDP) as the influencing parameters. A Logit Choice Model is used to divide the vehicle sales in ICE and EV categories. The input parameters used for the choice model are estimated TCO, and a perception factor. The perception factor is influenced by parameters such as policies, availability of public charging stations, vehicle choice range, resale value, EV awareness and driving range per charge. The estimated penetration was used to forecast EV fleets in select cities in 3 states i.e., Maharashtra (Mumbai, Pune, Nagpur, Thane, Nasik), Madhya Pradesh (Bhopal, Gwalior, Indore, Jabalpur) and Tamil Nadu (Chennai, Salem, Madurai, Coimbatore, Tirunelveli).

The results highlight higher penetration rates for fleet owned vehicles compared to personal vehicles in all segments. The 3W segment is expected to achieve the highest penetration level, followed by 2Ws. The combined EV penetration for the three segments is expected to be about 18% by 2030 (World Bank, 2022) (Figure 3.1).

3.1.2 Agent-Based Model

An agent-based model is a computational approach for simulating the actions and interactions of autonomous agents within a system. These agents can represent individuals, groups, organisations, or even inanimate objects, depending on the specific context of the model. The core idea is to understand the emergent behaviour of the system, which refers to complex and often unexpected patterns that arise from the collective interactions of the individual agents (Islamovic & Lind, 2021).

The agents' decisions are simulated basis their assumed characteristics, decision-making rules, and interactions that lead to emergent patterns at the system level. This methodology is often

Figure 3.1: EV penetration forecast by the World Bank (2022)

Market segment	FY21 ('000)	FY25 Sales ('000)	EV share (FY25)	FY30 ('000)	EV share (FY30)
2W personal	149	1,573	8%	3,423	15%
2W Fleet		557	12%	1,106	20%
4W Personal	5.9	140	4%	568	9%
4W Fleet		25	8%	89	17%
3W Fleet	88	159	46%	254	55%
3W Freight		51	33%	118	40%
Total	**243**	**2,505**	**12%***	**5,558**	**18%***

**Weighted average across market segments.*
Source: World Bank (2022)

used for vehicle technology adoption. However, its reliance on micro data for consumer attributes and the complexity of its validation process (Al-Alawi & Bradley, 2013) contribute to its inherent challenges.

A study by the Technology Information, Forecasting and Assessment Council (TIFAC) and NITI Aayog (TIFAC & NITI Aayog, 2022), estimates e-2W sales using an agent-based model. It simulates the decision making of buyers in different institutional, policy and technology scenarios. In this study, an agent's decision is influenced by its attributes (age, income etc.), plus vehicle attributes along with prevailing economic, technological, policy and market related factors.

The study developed eight (8) scenarios, and concluded that technology improvement, reduction in battery costs, and incentives were the most crucial parameters for accelerating adoption of EVs. In the optimistic scenario, with continued incentives, reduction in the battery cost (8% per annum) and factors like power and range improving overtime, the penetration rate was estimated to be above 90% by 2030 for the 2W segment. The penetration may be lower at 42% if the incentives were withdrawn after FY24, assuming everything else remained the same. The pessimistic scenario anticipates penetration of approximately 3%.

3.1.3 Diffusion Model (S-Curve)

Diffusion models are useful in predicting adoption and spread of a new technology, like EV, over a period. The S-curve is a visual representation of the diffusion process of an innovation or technology. It depicts three stages:

1. **Slow initial adoption:** This stage is characterised by a gradual increase in adoption as innovators and early adopters experiment with the new technology.
2. **Rapid growth:** This stage sees a significant acceleration in adoption as the technology gains traction and becomes mainstream.
3. **Maturity and saturation:** As the market becomes saturated, the rate of adoption slows down and eventually plateaus.

For adjusting the curve (gradient and final value), historical data is used together with expert judgment (Islamovic & Lind, 2021). Sometimes, time series is also used in combination. A 2023 study by RMI (RMI, 2023) suggests that EV penetration across countries is likely to expand along an S-curve. An exponential growth pattern for EV sales is evident in leading markets such as Northern Europe and China. A gradual increase in EV adoption is seen initially, with penetration rising from 1% to 10% in the first six years. Following this, a significant acceleration is seen, reaching over 50% penetration within the next six years (RMI, 2023).

3.1.4 Time Series Forecast

Time series forecast uses historic data to estimate growth trajectory of specified parameter(s) within a sequential dataset. There are different methods to deploy time series forecasting, each with its strengths and suitability for different context. These include Autoregressive Integrated Moving Average (ARIMA), Autoregressive Integrated Moving Average with Explanatory Variable (ARIMAX), Vector Autoregression (VAR), Neural networks etc. It is mostly used for short run but has also been used for medium and long term (Zhang, et al., 2017). Some studies such as Islamovic &Lind (2021), used a combination of time series and S-curve to construct a new equation that can be applied for long term.

3.1.5 Government Goals

This method utilises government targets to estimate the trajectory of product adoption. The underlying assumption is that the government will take necessary steps to achieve the announced targets. A CEEW study estimated total vehicle sales by applying government targets to forecast EV sales (CEEW, 2020) (Figure 3.2). This approach also adjusts for unforeseen future policies and interventions. It is best suited for countries with a stable and credible political regime.

3.2 EV Sales Scenarios - Methodology

EV scenarios were developed for two time periods i.e., medium term (2024-2030) and long term (2030-2047). This approach separates the medium term with relatively with less uncertainty, versus the long term with inherently higher degree of uncertainty.

Figure 3.2: EV sales forecast by CEEW (2020)

Vehicle Segment	Cumulative EV sales (FY21-30) (Million)			
	Low Adoption	Medium Adoption	Base case Adoption	High Adoption
2W	56	75	94	103
3W	2	2	3	3
Cars (Private)	2	2	3	3
Cars (Commercial)	1	2	2	2
Total	61	81	102	112
EV share in new vehicle sales in 2030	**23%**	**31%**	**39%**	**43%**

Source: CEEW (2020)

3.2.1 Medium-term Scenarios (2024-2030)

A two-step approach was adopted to develop EV sales scenarios. First, the total vehicle sales were estimated using times series analysis for different vehicle segments - 2W, 3W, 4W, bus and trucks (LCV and MHCV). A macro-economic parameter (real per capita GDP) was used as an exogenous variable. EV penetration rates were estimated under three different scenarios and combined to derive the likely EV sales (Figure 3.3).

It is emphasised that various scenarios represent a spectrum of probabilities. Depending on the evolution of technology, policy, regulation and market, different outcomes are possible within the scenario envelop. As such, these should be considered as possible pathways representing possible future development under different situations, rather than deterministic and discrete estimates. A normal probability distribution may be assumed across scenarios, meaning that scenarios around the mean are more likely. Explicit assumption or weighing has not been specifically adopted.

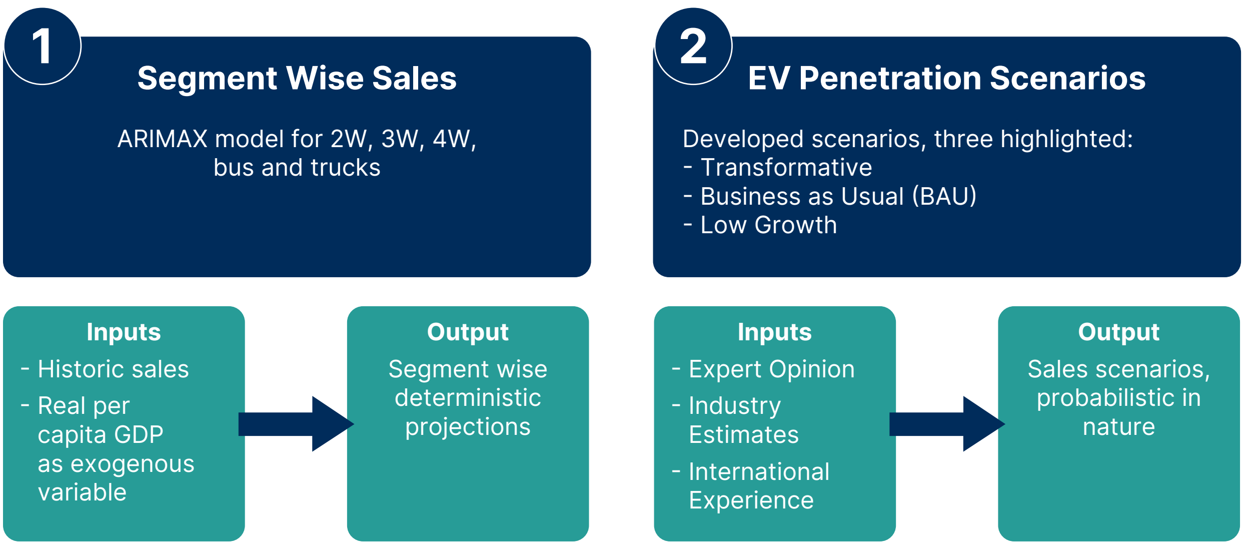
The methodology adopted is appropriate because EVs serve an existing need and are not a distinctively new product category. From the user perspective, they serve the same need as a traditional ICE vehicle. In any case, historical EV sales data is insufficient for econometric modelling. Considering both these aspects, adopting total vehicle sales for development of scenarios was considered appropriate. This approach of developing scenarios of vehicle sales based on a macro-economic outlook incorporates key drivers of demand curve. This serves as the upper bound for total EV sales. Penetration rates are a function of policy, price, and technology evolution (charging infrastructure and product). Therefore, international experience combined with expert judgement was used for estimating segment wise penetration rates.

a) Total Vehicle Sales Forecast:

Three different time series techniques were considered i.e., Auto-Regressive Integrated Moving Average (ARIMA), Vector Error Correction Model (VECM) and Auto-Regressive Integrated Moving Average with exogenous variables (ARIMAX).

The ARIMA model was first tested for stationarity using the Augmented Dickey-Fuller (ADF) and Kwiatkowski-Phillips-Schmidt-Shin (KPSS) tests, and for autocorrelation using the Ljung-Box test. Various combinations of Autoregressive (AR),

Figure 3.3: Framework for medium-term scenarios (2024-2030)



Source: RTI Analysis

Integrated (I), and Moving Average (MA) terms were explored to identify the optimal model fit.

Vector Error Correction Model (VECM) was parallelly investigated to understand how different vehicle segment sales influence each other over time. VECM helps analyse both long-term stability and short-term changes in these relationships. However, in many cases, the segment-wise sales were found to lack cointegration. As a result, its usefulness was limited for this study.

Real per capita Gross Domestic Product (GDP) was incorporated as an exogenous variable as it demonstrated high correlation with total vehicle sales. An ARIMAX model was constructed, tested and assessed. To mitigate the influence of outliers and noise, it was constructed with locally estimated scatterplot smoothing (LOESS). This technique proved to be the most relevant in out-of-time (OOT) validation among all the models tested.

b) Scenario Development:

Secondary research and primary inputs as mentioned below were used for arriving at estimates for different vehicle categories.

1. **Expert Opinion:** Primary inputs were obtained from stakeholders in the automobile industry and the insights obtained were appropriately incorporated for developing scenarios.
2. **Secondary Industry Estimates:** A review of annual reports, business plans, and announced projects was conducted. These forecasts were deemed significant as the industry invests based on the same.
3. **International Experience:** Different countries are at different stages of EV adoption. International experience provides valuable insights for potential trajectory in India. EV penetration in seven countries i.e., Norway, China, UK, US, South Korea, Brazil, and Mexico was reviewed (See Annexure 3.3 for detailed country wise policies). Each of these countries have undergone an evolution in EV adoption for over a decade.

Based on the above, three possible scenarios were constructed, as mentioned below:

1. **Transformative:** This scenario presupposes rapid technological evolution and supportive policies at the centre and state levels. It further assumes that other stakeholders, such as city administration, DISCOMs and financial institutions are well aligned and supportive.
2. **Business-as-Usual (BAU):** This scenario assumes continuation of existing policies and prevailing market trends.
3. **Low Growth:** In this case, EV penetration remains low based on slow evolution of technology and market, as well as tapering government support.

Data Sources: Historical vehicle sales data was obtained from the Society of Indian Automobile Manufacturers (SIAM). Segregation of commercial vehicles into Bus, LCV and MHCV was done by using data from the Vahan Dashboard. The real per capita GDP data was obtained from the World Bank data set, while the forecasted values were from the OECD database (see Annexure3.1). Historical EV sales were obtained from the Vahan Dashboard.

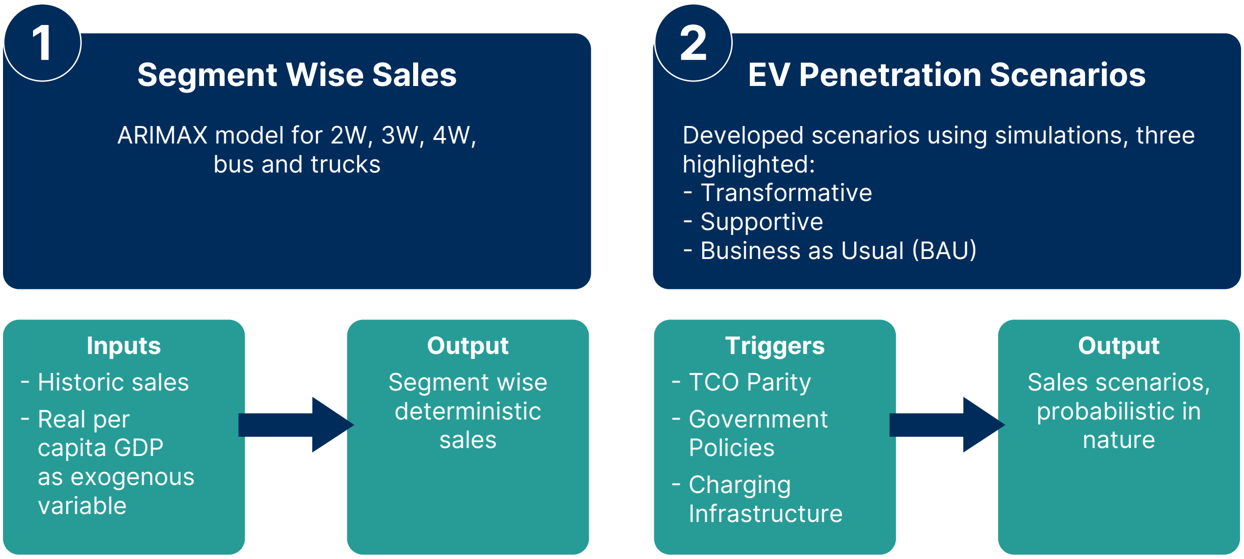
3.2.2 Long-term Scenarios (2030-47)

A different approach was adopted for developing long term scenarios given the greater uncertainty. The framework adopted is presented in Figure 3.4.

a) Total Vehicle Sales:

As in the case of the medium term, vehicle sales estimates were constructed using the time series ARIMAX model. Given that India will remain a developing country in the reference period, this approach remains applicable. A structural break, such as rapid acceleration of public transport is not evident and therefore econometric models based on real per capita income provide a reasonable estimate of the future.

Figure 3.4: Framework for long term scenarios 2030-2047



Source: RTI Analysis

b) Scenario Development

International Experience: Evidence from international experience was used to identify triggers, such as policies and incentives that had a major impact on EV sales and penetration. Markets in seven countries were reviewed, including the ones that have made significant progress in EV penetration like China, Norway, South Korea, UK, USA, Brazil, and Mexico.

This analysis revealed three main levers i.e., TCO, Policy Support and Charging Infrastructure that had the largest impact. Their impact was estimated, and central values were calculated. It was not possible to precisely isolate the impact of each trigger individually, but the range and central values provide a fairly accurate estimate of their potential. Therefore, this analysis was used as one of the inputs, supplemented with other factors.

Supportive government policies increased EV penetration by about 6 times (average value across countries), over a period of 4 years for cars and buses. The impact was almost double for vans. Similarly, expansion of charging infrastructure also led to a six-fold increase in EV penetration for cars, fivefold for vans and four-fold for buses, over a period of 4 years. The data on trucks was limited (See Annexure 3.2 for Detailed Table).

For developing scenarios, one or more of these three triggers was assumed likely to occur during the 2030-47 period. This was assumed given the policy push towards decarbonisation, focus on improving air quality and support for EVs, particularly in the mass segment and public transport. To capture all possible combinations, several scenarios were constructed (Figure 3.5). Given the expectation of pick-up in e-mobility by 2030 under various medium-term scenarios, and likely technological advances, long-term analysis focuses on scenarios with one or more positive triggers. BAU scenario is based on continuation of prevailing market trends in 2030.

In case of medium-term analysis, various scenarios represent a spectrum of probabilities. Depending on the evolution of technology, policy, regulation and market, different outcomes are possible within the scenario envelop. As such, these should be considered as possible pathways representing future development under different situations, rather than deterministic and discrete estimates. A normal probability distribution may be assumed across scenarios, meaning that scenarios around the mean are more likely, though explicit assumption or weighing has not been specifically adopted.

1. **Transformative:** Represents a scenario with all three triggers occurring simultaneously during the reference period.
2. **Supportive:** Represents scenarios with one or two triggers.
3. **BAU:** Represents the business as usual (BAU) scenario, with no incremental triggers.

Scenarios were developed for each of the segments separately considering the three triggers as mentioned in Figure 3.5. By 2030, TCO will likely be achieved for all segments except trucks, and therefore that trigger was considered positive across the segments.

For trucks, all three triggers can assume positive or negative values. Two supportive scenarios i.e., high support (two positive triggers) and low support (one positive trigger) were therefore developed.

Simulations: Given the long horizon, it was not possible to precisely determine the timing of occurrence of a trigger i.e., when a trigger will occur was considered uncertain i.e., probabilistic in nature. Occurrence of triggers was therefore randomised, with a large number (i.e., over 1000) of simulations. Occurrence of a trigger boosts the penetration rate based on a combination of factors. For each of the scenarios, simulations were performed, and a mean value was derived for the results.

In the BAU scenario, only E2Ws are likely to achieve 100% adoption ahead of 2047. In the supportive scenario, E3Ws and E-Bus segments also achieve near 100% penetration by 2047.

E4Ws are likely to achieve 100% penetration in the transformative scenario. Compared to the above mentioned three segments, 4Ws would need a stronger policy and infrastructure support to reach 100% adoption levels.

E-Trucks, unlike other segments, are expected to achieve a penetration rate between 34% to 59% by 2047. It is a difficult segment to electrify and would require prolonged support from the government.

Thus, all segments, except trucks are likely to achieve 100% EV penetration in at-least one of the scenarios by 2047.

The overall penetration levels are likely to be in the 90-99% range by 2047. This may translate into potential EV sales of 68 – 74 Million units.

3.3 Results

This section presents results for both, the medium and the long term. As explained, in each case, a two-step process was adopted to develop the scenarios. In the first step, the total sales are estimated and then combined with penetration scenarios to estimate total EV sales for each segment. Estimates from secondary sources are presented before the results to provide a context to this analysis.

Figure 3.5: Scenarios constructed for 2030-47

Parameter	BAU	Supportive		Transformative
		Policy support	Charging Infrastructure Support	
Policy	No	Yes	No	Yes
Charging Infrastructure	No	No	Yes	Yes
TCO	Yes	Yes	Yes	Yes

Source: RTI Analysis

3.3.1 Two-Wheelers

a) *Secondary Estimates:*

Various secondary estimates suggest annual sales penetration of E2W to be in the range of 30% to 75% by 2030. The lowest estimate is 30% (ICRA, 2023) while the highest projection is 75% (KPMG, 2023). The average industry estimate is around 35%-40% with absolute EV sales range between 9 Million and 22 Million (Annexure 3.2).

b) *Results – Medium-term Scenarios (E2W):*

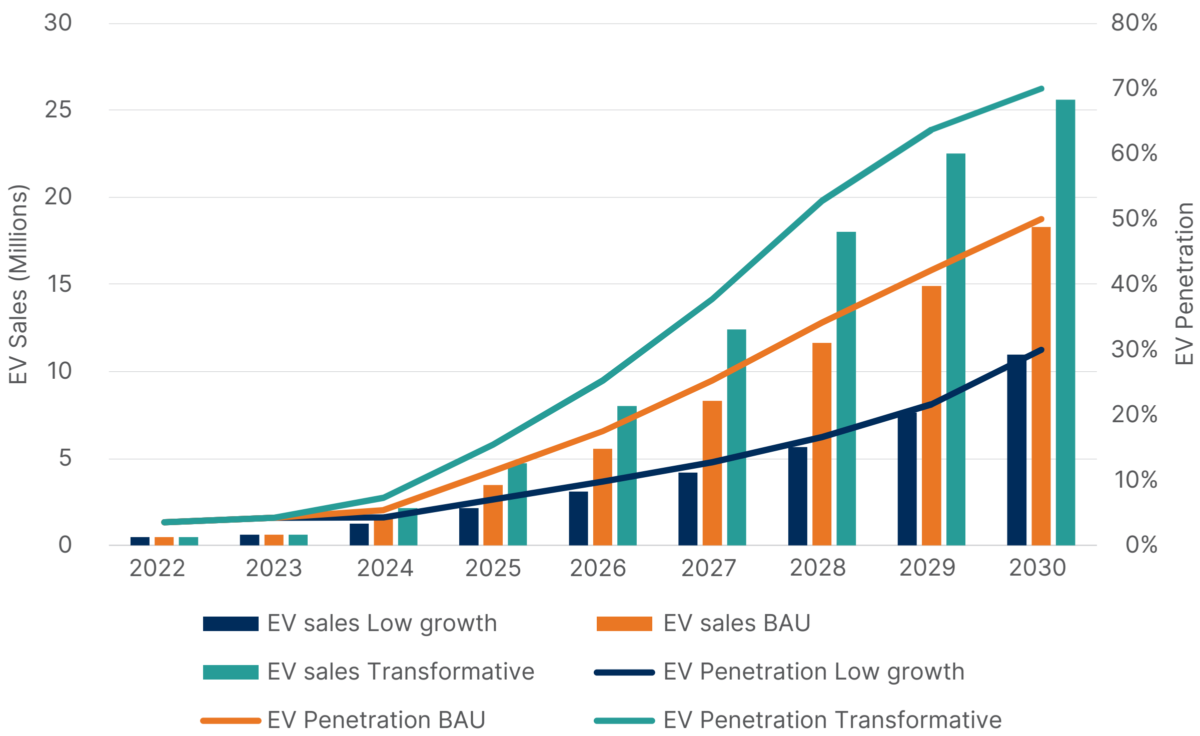
E2W sales are likely to be between 11 to 26 Million units by 2030. The penetration rate is expected to be in 30-70% range (Figure 3.6).

In the low adoption scenario, penetration rate of 30% is likely with potential sales of up to 11 Million units while penetration may rise to 50% in the BAU case with sales of up to 18 Million units. In the transformative scenario, penetration may reach 70%, with potential sales of up to 26 Million units.

With the TCO parity already achieved, the E2W market is likely to grow rapidly. Entry of large players like Bajaj, Suzuki and Honda in the market is likely to give it a further boost. New models such as Bajaj Sunny, Honda Activa electric and Suzuki Burgman Electric are expected to be launched in 2024 with improved battery range and features. It is also likely that dominant startups in this sector such as Ola electric, Ather, Okinawa, etc. will innovate and introduce newer products in response. Ola Electric's recent launch of electric motorbikes called Roadster series with a starting price of INR 74,999 is one such example which may potentially expand the market for E2Ws.

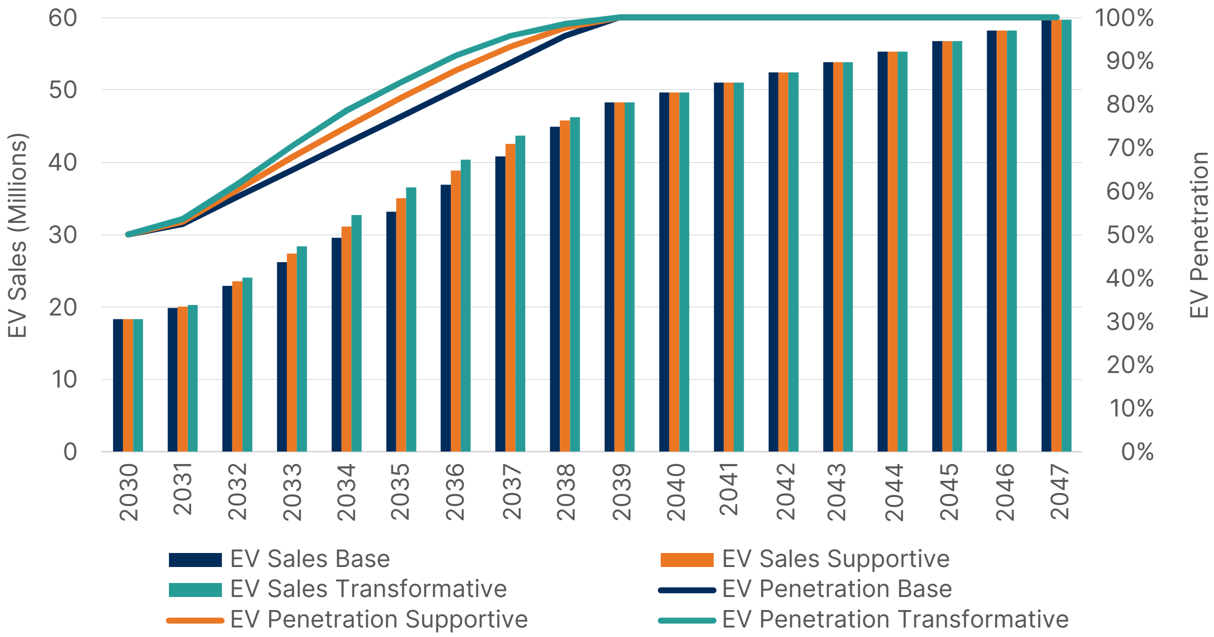
In addition, E-commerce players like Amazon, Flipkart and BigBasket have adopted EV targets. In 2020, Amazon India announced to include 10,000 EVs in its delivery fleet by 2025, with an overall target to achieve net-zero carbon by 2040. Similarly, Flipkart has pledged to transition to EVs by 2030. Such initiatives are likely to increase demand in the medium term.

Figure 3.6: E2W medium term scenarios



Source: RTI Analysis

Figure 3.7: E2W long term scenarios



Source: RTI Analysis

c) *Results – Long-term Scenarios (E2W:*

The long-term analysis suggests that E2W will likely be widespread under the BAU scenario i.e., 100% penetration by 2039, with likely sales of up to 48 Million units (Figure 3.7).

Given that the market is evolving rapidly, it is likely that by 2030 a significant proportion of users may have already adopted EVs. Therefore, various long-term scenarios tend to converge, signalling lower uncertainty. By 2047, E2W sales could reach a potential peak of around 60 Million units.

3.3.2 Three-Wheelers

a) *Secondary Estimates:*

In case of E3W penetration, various estimates are in the range of 50-90% by 2030. ACMA suggests a penetration level of around 66% (ACMA, 2021), McKinsey provides a similar estimate of 60-65% (McKinsey, 2020) while KPMG has a higher penetration target of 90% (KPMG, 2023). The average of these estimates is in the 65-70% range (Annexure 3.2).

Many auto experts share an optimistic outlook for E3W. As per EV maker Lohia Auto, 'The three-wheeler segment will be the first one to transition entirely to EVs' (ET Energyworld, 2023).

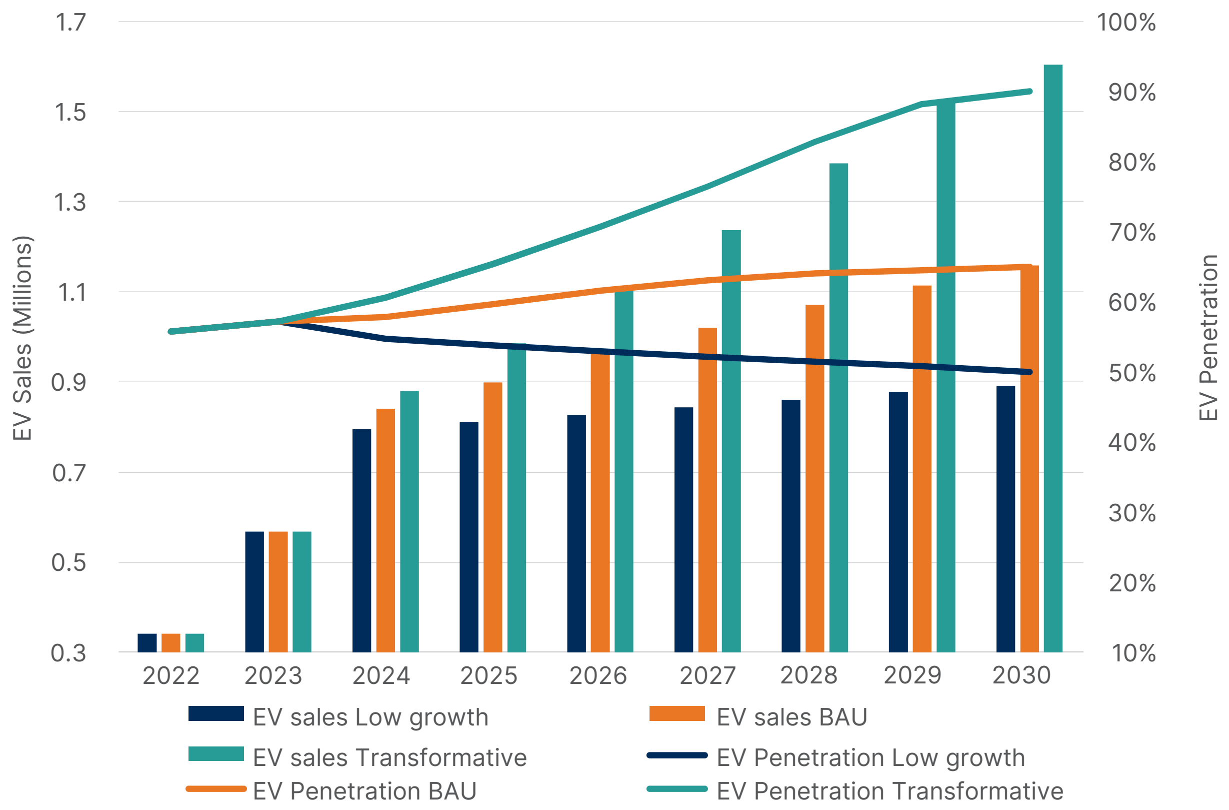
b) *Results – Medium-term Scenarios (E3W):*

E3W sales are likely to be between 0.9 to 1.6 Million units by 2030 with the penetration rate expected to be in the 50-90% range (Figure 3.8).

In the low adoption scenario, penetration rate of 50% is likely, with potential sales of up to 0.9 Million units. This is close to the current rate, suggestive of a flat to marginally downward trend with the understanding that yearly rates may fluctuate around 50% mean value. In the BAU case, penetration may increase to 65%, with potential sales of up to 1.2 Million units. In the transformative case, penetration may reach 90%, with potential sales of up to 1.6 Million units.

As such, the market for E3Ws appears to be positive and on an upswing. There are positive market developments on both, i.e., the demand

Figure 3.8: E3W medium term scenarios



Source: RTI Analysis

and the supply side. On the demand side, there is a momentum for passenger transport as well as commercial fleets. For example, Amazon India has tied up with TVS for electric two and three-wheeler deployment; Flipkart has partnered with leading EV manufacturers Hero Electric, Mahindra Electric and Piaggio to transition its fleet to electric. E3W commercial fleet segment is expected to scale rapidly.

There is significant activity on the supply side as well, with many new models being launched. Altigreen has launched a new E3W model 'neEV Tez' with improved charging speed. Mahindra recently launched 'Zor Grand' and claims to have received over 14,900 bookings through strategic MOUs with leading logistics companies. Further, some of the MSME players are also working towards launching products in this segment.

Improvements in battery swapping infrastructure has reduced the range anxiety and overall EV ownership costs for E3Ws. Budget FY23 also announced introduction of battery swapping policy and interoperability standards.

c) *Results – Long-term Scenarios (E3W):*

E3W market is likely to reach 90% penetration by 2047 in the BAU case, with potential sales of up to 2.5 Million units. In the supportive scenario, the penetration is likely to be around 100% by 2047. Transformative scenario could potentially accelerate 100% adoption by a few years.

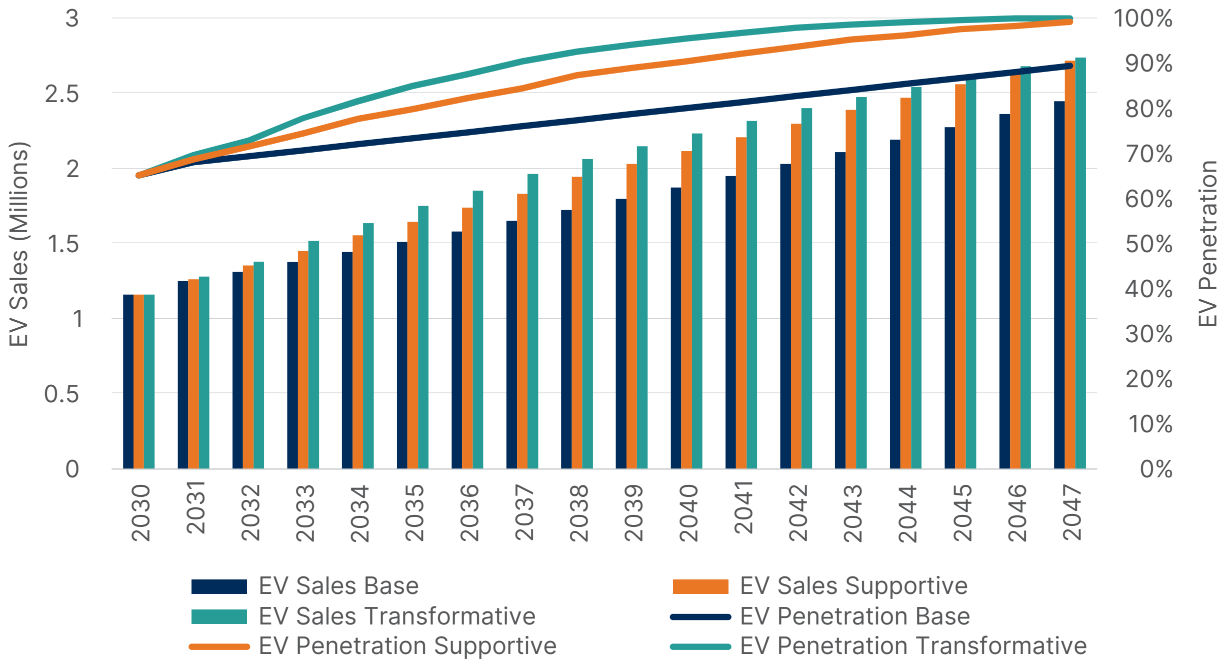
All long-term scenarios exhibit high penetration rates with tapering growth closer to the saturation level. By 2047, E3W sales are likely to be around 2.7 Million units (Figure 3.9).

3.3.3 Four-Wheelers

a) *Secondary Estimates:*

Various studies suggest that EV penetration in 4W segment may be in the 12-20% range by

Figure 3.9: E3W long term scenarios



Source: RTI Analysis

2030. ACMA and IEA provide an estimate of about 13% penetration (ACMA, 2021) (IEA, 2023), while Bain estimates 15-20% penetration (Bain & Company, 2022). Both KPMG and ICRA estimate 15% penetration (KPMG, 2023) (ICRA, 2023).

In terms of the absolute sales, estimates vary between 0.4 Million units to about 1 Million units. ACMA's estimate of 0.55 Million is in the middle of the range while IEA estimates sales to be around 0.9 Million (Annexure 3.2).

International experience suggests that countries attained varying levels of penetration in a decade. While Norway demonstrated accelerated progress with 88% penetration, China and UK attained 20-30% penetration, followed by South Korea and US with about 10% penetration (Annexure 3.2).

As it is evident, Norway can be considered an exception with a very high penetration. An interesting feature of the Norwegian electricity mix is that almost the entire generation is based on hydropower. Most other countries have achieved penetration rates below 25% by 2022, but growth has picked up in the recent years.

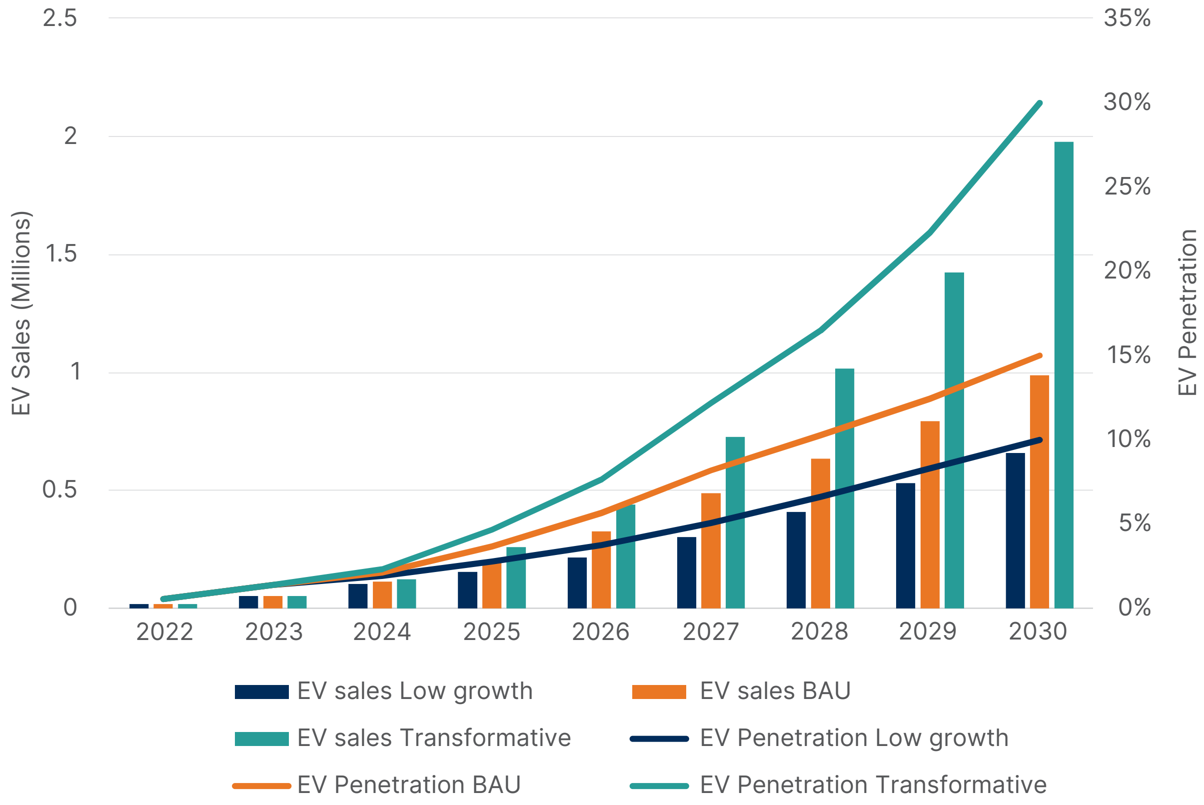
b) Result – Medium-term Scenarios (E4W):

E4W sales are likely to be in the range of 0.6 - 2 Million units by 2030 with the penetration rate expected to be in 10-30% range (Figure 3.10).

In the low adoption scenario, penetration rate of 10% is likely, with potential sales of up to 0.6 Million units. In the BAU case, penetration may rise to 15%, with potential sales of up to 0.9 Million units while in the transformative case, penetration may reach 30%, with likely sales of up to 2 Million units.

Overall, the future looks favourable because of lowering of the TCO and improving charging infrastructure availability over time. TCO parity with diesel and petrol variants is already achieved for a few 4Ws, especially in the small car segment and parity with CNG variants is expected in the next few years. Declining battery costs, improved access to financing (especially in large cities), and government incentives will likely reduce the TCO even further.

Figure 3.10: E4W medium term scenarios



Source: RTI Analysis

Charging infrastructure availability will likely improve if the proposal to setup 46,397 Public Charging Stations (PCS) by 2030 in nine major cities is implemented. Private sector is also investing, with players such as Tata Motors setting up charging stations and developing associated Apps to locate them.

Commercial 4W fleet is likely to transition to electric more rapidly. New players like BluSmart Mobility are gaining significant traction with its all-electric fleet. Similarly, Uber introduced electric cabs under the 'Uber Green' brand in Delhi, Mumbai, and Bengaluru.

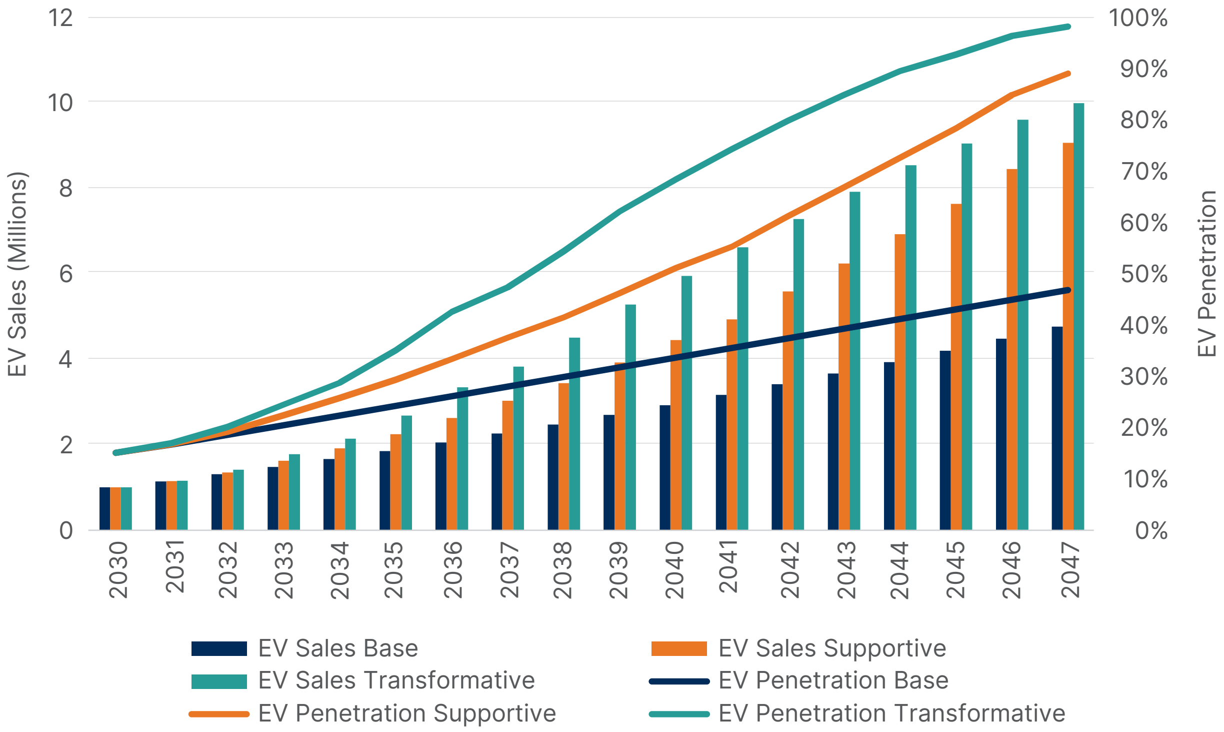
However, the evolution will depend on several factors beyond direct control of the EV industry. Apart from TCO, charging infrastructure and incentives, sales will likely be impacted due to competition from mild and strong hybrids. In 2023, hybrid car sales surpassed electric car sales for the first time. Hybrids also form a significant share of total 4W sales in countries like Norway and China. The Department for Promotion of Industry and Internal Trade (DPIIT) and the Ministry of Heavy Industries are considering rationalising taxes on hybrid passenger vehicles (Reuters, 2024).

Further, the industry has made significant investments to comply with BS VI norms. The Government of India has also been promoting biofuels, as well as investments in CNG by awarding City Gas Distribution licences. Therefore, it is fair to assume that E4Ws will continue to co-exist with improved low emission ICE vehicles.

c) *Long-term Sales Scenarios (E4W):*

E4Ws are likely to reach 47% penetration by 2047 with potential sales of up to 5 Million units under the BAU scenario. IEA has a similar projection of penetration of more than 40%, by 2050.

Figure 3.11: E4W long term scenarios



Source: RTI Analysis

In the supportive scenario, about 90% penetration by 2047 is likely, with potential sales of about 9 Million units. In the transformative scenario, about 100% penetration may be achieved by 2047, which is likely to translate into potential sales of about 10 Million units (Figure 3.11).

3.3.4 E-Buses

a) Secondary Estimates:

NITI projects a penetration rate of 13-16% for electric buses by 2030 (MHI, 2024) while the industry estimates are in the 12%-40% range. The external estimates for annual sales suggest a range of 17,000 to 35,000 by 2030 (Annexure 3.2).

International experience suggests that on an average, 10-15% penetration levels were achieved by various countries in about a decade. Norway achieved the highest penetration (40-50%), followed by UK and China (10-15%). Countries like South Korea and Brazil had low penetration of less than 2% by 2022 (Annexure 3.2).

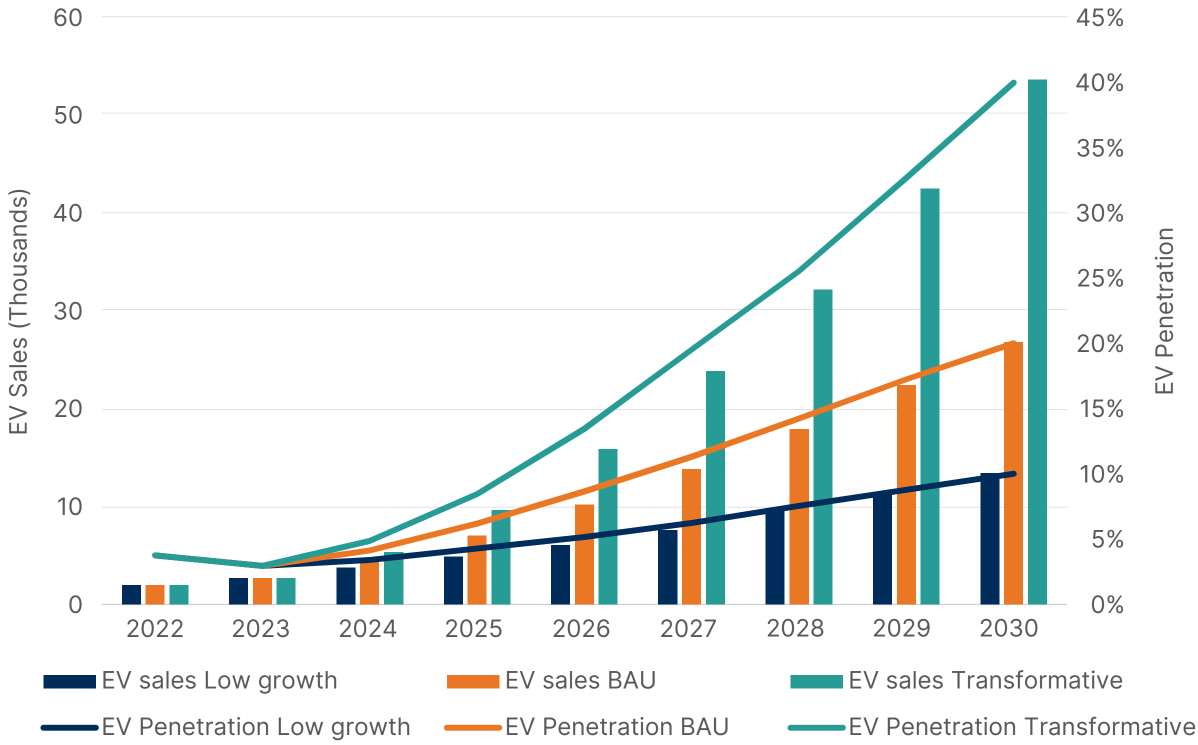
b) Results – Medium-term Scenarios (E-Bus):

E-Bus sales potential is in the range of 13 - 54 thousand units in 2030, with a likely penetration rate between 10-40% (Figure 3.12). In the low adoption scenario, penetration rate of 10% is likely, with potential sales of up to 13,000 units. In the BAU case, penetration may be 20%, with potential sales likely to be approximately 27,000 units. In the transformative scenario, potential sales may be 54,000 units, with a likely 40% penetration level.

With some states establishing targets to transition their public bus fleets to electric, the E-bus market is likely to expand. Delhi is targeting 80% of its bus fleet to be electric by 2025. Similarly, Kerala aims for 6000 electric buses by 2025.

Efforts to accelerate adoption are being made by various stakeholders for example, high upfront cost is being addressed through the GCC (Gross Cost Contract) model. The government is developing a Payment Security Mechanism

Figure 3.12: E-Bus medium term scenarios



Source: RTI Analysis

(PSM) with a contribution of USD 240 Million. Other sources such as the US government are expected to contribute about USD 150 Million. This is expected to support large-scale rollout of 38,000 electric buses across the country (PIB, 2023).

There is explicit policy and program support from the central and state governments for E-Buses. Therefore, E-Bus sales are expected to grow steadily in the BAU scenario and more rapidly under the transformative scenario. In the latter case, transition of private ICE buses will be crucial.

c) Results – Long-term Scenarios (E-Bus):

The E-Bus segment is likely to reach 52% penetration by 2047, with potential sales of up to 0.1 Million units under the BAU scenario.

In the supportive scenario, the segment is likely to reach 96% penetration by 2047, with potential sales of about 1.9 Million units. In the transformative scenario, it is likely to attain 100% penetration by 2047 which will translate into potential sales of up to 0.2 Million units (Figure 3.13).

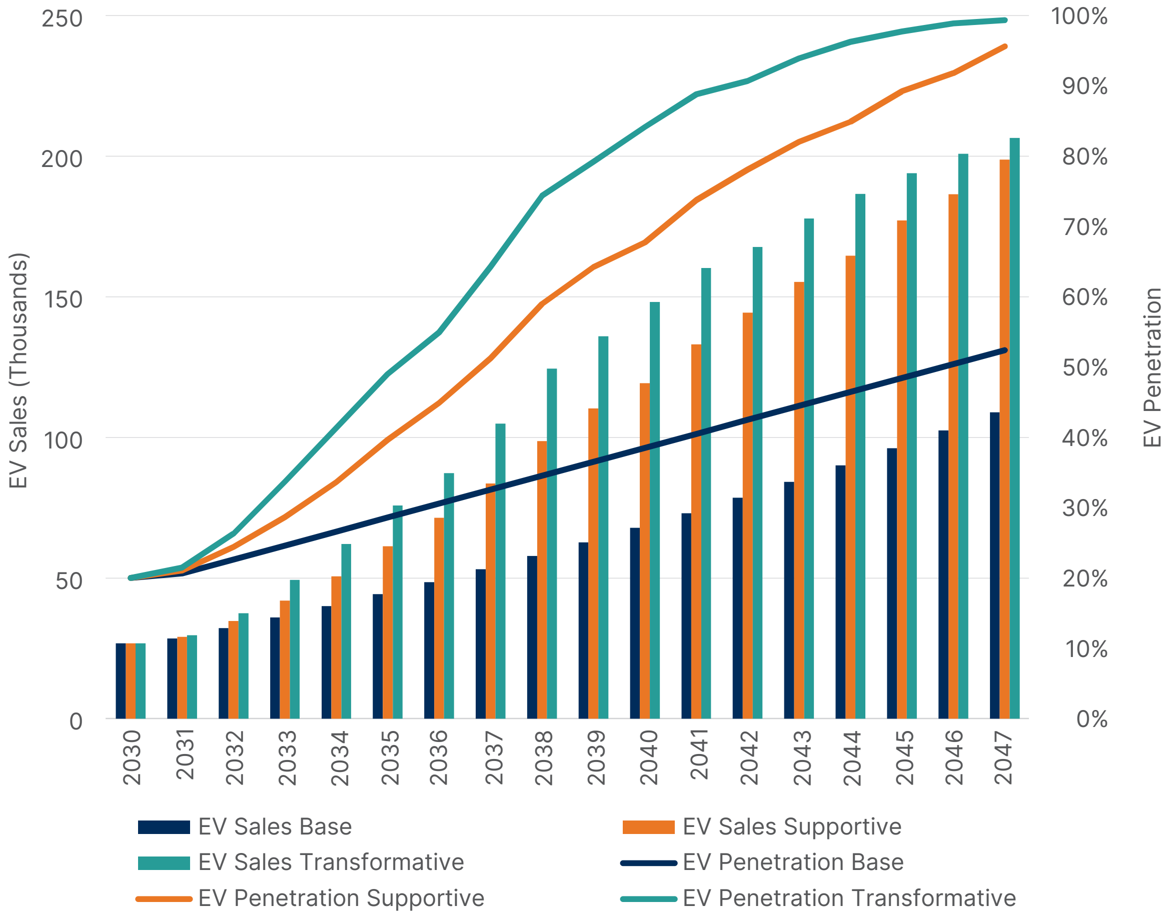
3.3.5 E-Trucks

In the case of trucks, the scenarios were developed separately for the LCV segment which seems to be driving the adoption, versus the MHCV category. Significant uncertainty persists around adoption of e-trucks particularly for MHCVs, due to uncompetitive economics and lack of charging infrastructure. Further, because of technology competition with hydrogen fuel cell trucks, the sales scenarios can be considered to correspond to zero emission trucks, particularly in the long-term.

a) Secondary Estimates:

Various studies suggest that the small truck category is likely to undergo faster transition to EVs compared to the heavy and medium

Figure 3.13: E-Bus long term scenarios



Source: RTI Analysis

trucks. E-LCV (below 3.5 tonnes) estimates range between 10-73% penetration and ACMA estimates 10% penetration by 2030 (ACMA, 2021). As per an analysis by Ashok Leyland, E-LCV will grow at a rate of 73% between FY24-FY32 with estimated sales of about 3 lakh E-LCVs in FY32 (Ashok Leyland, 2023).

For the medium and heavy electric trucks, Bain expects a penetration of 2-5% by 2030 (Bain & Company, 2022) with volumes to be around 15,200 - 38,000 units. The IEA forecasts 10,600 MHCV sales in 2030 (Annexure 3.2).

According to BNEF, sales of large trucks may accelerate rapidly over the next decade (Bloomberg, 2023). As per RMI and NITI, with supportive polices, ZETs can potentially achieve an 85% sales penetration by 2050 (RMI & NITI Aayog, 2022).

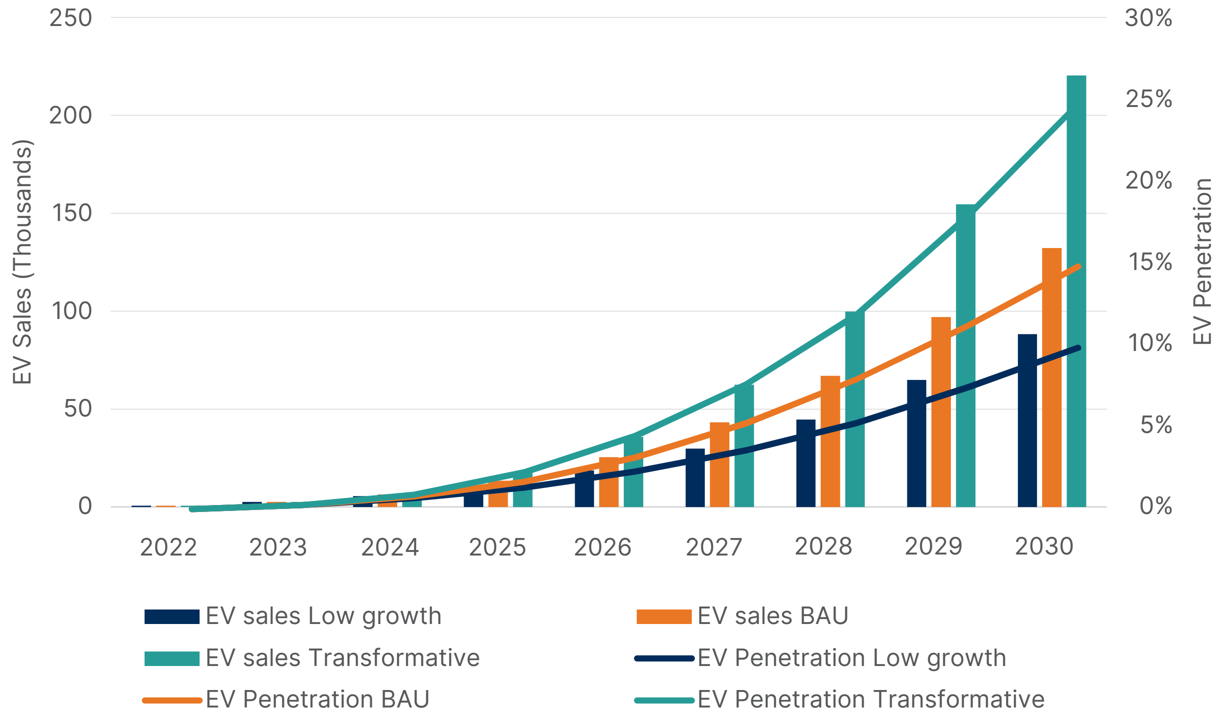
Internationally, the experience has been positive particularly in the LCV segment. The average penetration for LCVs achieved by various countries in a decade was about 12% with countries like South Korea and Norway leading the way with penetration rates of 25% by 2022.

For MHCVs, average penetration is around 3%. China and Norway have attained 4-6% penetration, while UK and Brazil are below 2% (Annexure 3.2).

b) Results – Medium-term Scenarios (E-Truck):

LCVs form about 70% of the total truck sales as per Vahan Dashboard. By 2030, E-LCV potential sales are likely to be in the range of 88,000 – 221,000 units, with penetration rate likely to be between 10-25% (Figure 3.14).

Figure 3.14: E-LCV medium term scenarios



Source: RTI Analysis

In the low adoption case, penetration rate of 10% is likely, with potential sales of around 88,000 units. In the BAU case, penetration may increase to 15%, with potential sales of up to 130 thousand units. In the transformative scenario, potential sales may reach 220 thousand units with penetration level likely to be 25%.

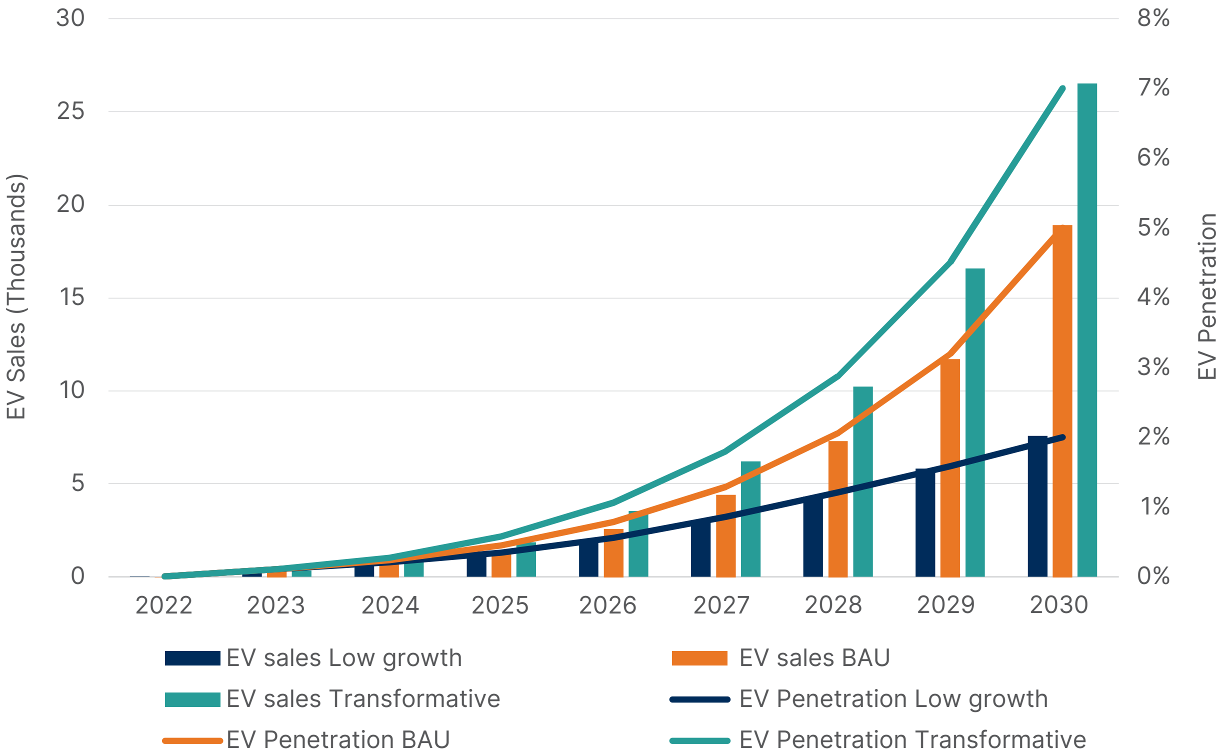
Compared to this, E-MHCV sales will likely attain a relatively low penetration rate between 2-7% by 2030 with corresponding sales likely ranging between 8-26 thousand units. In a low adoption scenario, the penetration is likely to remain around 2%, with potential sales of around 8,000 units. Under BAU, the penetration may increase to 5%, with potential sales of about 19,000 units. In the transformative scenario, the penetration is likely to reach 7%, with potential sales of about 27,000 units (Figure 3.15).

LCVs are expected to scale rapidly in the next few years. It is possible that a demand incentive for purchase of E-trucks may be provided under the FAME III, which is currently under discussion (ET Auto, 2023). Further, government is also considering charging stations on highways. Various states such as Haryana, Madhya Pradesh, Himachal Pradesh, and Telangana considering provision of fast charging stations and battery swapping infrastructure on prominent highways as per their respective state mobility policies. Some progressive companies are targeting to move their fleets entirely to EVs. For example, IKEA announced in August 2024 that it will electrify all its deliveries in India by 2025.

TCO parity is not yet achieved for the truck segment. However, with reduction in battery costs, improvements in local capacities and government incentives, the TCO parity may be achieved within a decade for several segments.

However, other factors may act as a damper to the growth of electric trucks. Technological competition from Hydrogen Internal Combustion Engine (H2ICE) and Fuel Cell

Figure 3.15: E-MHCV medium term scenarios



Source: RTI Analysis

Figure 3.16: Implied stakeholder views on potential of various MHCV technologies

Stakeholder	Segment	Likely powertrain technology trend
Ashok Leyland	MHCV trucks	LNG
	Intermediate CV trucks	CNG, H2ICE
	LCV	EV, CNG
	Intermediate CV Bus	CNG, EV
	MDV Bus	CNG, EV
TATA Motors	MHCV & Intra city buses	FCEV and H2ICE (Demo projects developed)
Daimler	Intra-city segment	EV
	Inter-city segment	Hydrogen
GoI (MNRE)	Fuel cell vehicles	Low potential (till 2030)
Industry Perspective*	Passenger cars and buses	Hydrogen**
	TCO parity of FCEV with EV	10 years
	TCO parity of EV and FCEV with ICE vehicles	12-15 years

***H2 adoption can start with passenger cars and Bus segments*

*Source: Ashok Leyland (2023); MNRE (2023); * - McKinsey & Co. (2017); Stakeholder Consultations*

Electric Vehicle (FCEVs) is one such factor. This is particularly true for the medium and the heavy truck segments. Industry players like Ashok Leyland and Tata Motors have already developed prototypes of hydrogen powered trucks. However, the Hydrogen technology is still evolving and challenges such as high costs and safety are yet to be adequately addressed. There are different views on the most suitable technology for the MHCV segment within the industry (Figure 3.16).

Another factor is the potential modal shift of freight to railways, that may reduce the overall demand. Six dedicated freight corridors are being developed, of which two are near completion. The National Rail Plan envisages to increase the share of freight traffic by rail from the current 27% to 45% by 2030 (PIB, 2022).

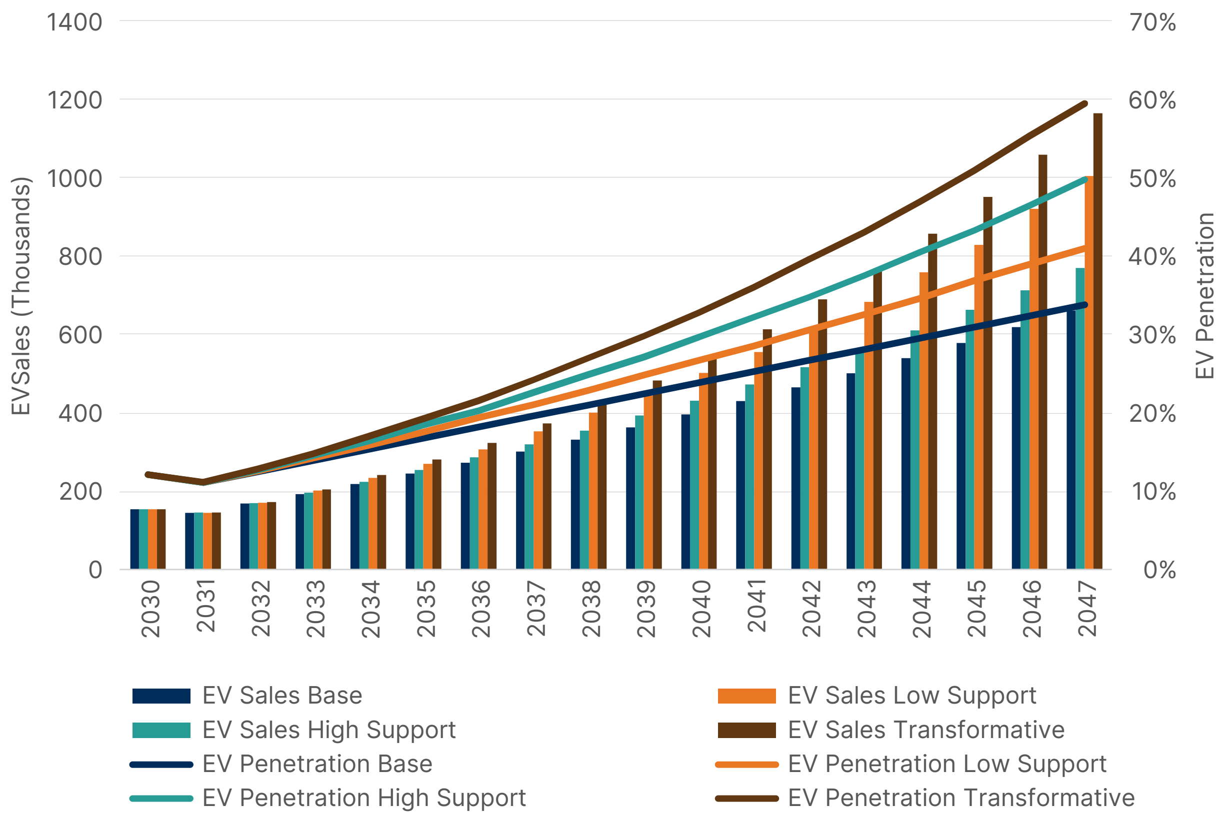
c) *Results – Long-term Scenarios (E-Truck):*

Electric trucks are likely to achieve 34% penetration by 2047 in the BAU scenario, with potential sales of up to 0.66 Million units.

In the supportive scenario, the penetration level may be in 41% - 50% range with potential sales of up to 0.77 - 1 Million. In the transformative case, 59% penetration level is likely, which may translate into potential sales of up to 1.2 Million units in 2047 (Figure 3.17).

It is emphasised that there is significantly higher uncertainty in this segment because of various factors mentioned above and therefore, actual outcomes outside of the scenario envelop cannot be ruled out. Also, because of the technological uncertainty, in the case of MCHV segment, E-trucks should be interpreted more broadly as zero emission trucks.

Figure 3.17: E-Truck long term scenarios



Source: RTI Analysis

3.3.6 Summary and Analysis

a) Medium Term:

Overall results show that segment wise penetration under the BAU scenario will witness continued progress towards adoption of EVs, particularly in 2W, 3W and E-bus segments (Figure 3.18).

This analysis suggests that a penetration rate of 44% under the BAU scenario by CY 2030, is somewhat higher than NITI Aayog's 30-35% (NITI Aayog and BCG, 2022) estimate by FY30. The differences may be attributed to inclusion of more recent data in this analysis, duration of the forecast, and other methodological considerations. In any case, as noted, the projections are probabilistic in nature and therefore point to point comparisons are not material for drawing policy or market conclusions.

The total electric vehicle sales in 2030 are likely to be 20.6 million in the BAU scenario. In the low growth scenario, the penetration is likely to be about 27%, with potential sale of about 12.5 Million units. On the other hand, in the transformative scenario, potential sales of up to 29 Million may be achieved with a penetration rate of 64% by 2030. To summarise, total EV sales are likely to be in the 12-30 Million range with penetration in 27-64% range (Figure 3.19).

The Clean Energy Ministerial, CEM's EV30@30 campaign focused on electric passenger cars, light commercial vans, buses, and trucks,

Source: RTI

Figure 3.18: Medium term scenarios for EV penetration (2030)

Scenario	E2W	E3W	E4W	E-Bus	E-Truck		Overall
Overall					E-LCV	E-MHCV	
Transformative	70%	90%	30%	40%	25%	7%	64%
BAU	50%	65%	15%	20%	15%	5%	44%
Low Growth	30%	50%	10%	10%	10%	2%	27%

Source: RTI Analysis

Figure 3.19: Medium term scenarios for EV sales (2030)

	EV Sales (Millions)		
Vehicle Segment	**Low Growth**	**BAU**	**Transformative**
2W	10.9	18.3	25.6
3W	0.9	1.2	1.6
4W	0.6	0.9	1.9
Bus	0.01	0.03	0.05
Truck -LCV	0.09	0.1	0.2
Truck -MHCV	0.008	0.02	0.03
Total	12.5	20.6	29.4

Source: RTI Analysis

with targets achieving a penetration of 30% in these categories. This analysis reveals that achieving this goal is ambitious and may be possible only in scenarios closer to the transformative case. This also indicates need for increasing policy support, in addition to improved charging infrastructure and technological advancements to accelerate penetration in these segments.

b) Long Term

In the BAU scenario, only E2Ws are likely to achieve 100% adoption ahead of 2047. In the supportive scenario, E3Ws and E-Bus segments also achieve near 100% penetration by 2047.

E4Ws are likely to achieve 100% penetration in the transformative scenario. Compared to the above mentioned three segments, 4Ws would need a stronger policy and infrastructure support to reach 100% adoption levels.

E-Trucks, unlike other segments, are expected to achieve a penetration rate between 34% to 59% by 2047. It is a difficult segment to electrify and would require prolonged support from the government.

Thus, all segments, except trucks are likely to achieve 100% EV penetration in at-least one of the scenarios by 2047.

The overall penetration levels are likely to be in the 90-99% range by 2047. This may translate into potential EV sales of 68 – 74 Million units (Figure 3.20).

Figure 3.20: EV sales and penetration long term scenarios (2047)

	BAU		Supportive		Transformative	
	Penetration	Sales (Million)	Penetration	Sales (Million)	Penetration	Sales (Million)
2W	100%	60	100%	60	100%	60
3W	89%	2.4	99%	2.7	100%	2.7
4W	47%	4.8	89%	9	98%	10
Bus	52%	0.1	96%	0.19	99%	0.2
Trucks	34%	0.7	41-50%	0.8-1	59%	1.2
Total	**90%**	**68.0**	**97%**	**72.8**	**99%**	**74.1**

Source: RTI Analysis

Source: RTI

4. COMPONENTS DEEP DIVE

Within a decade, the internal combustion engine automobile is likely to look exactly like what it is - a machine that converts gasoline into much more heat than forward motion, a bizarre antiquity.

Stephen Petranek

Source: RTI

Powertrain, Power Electronics and Software

This chapter describes the supply-side dynamics of the EV components industry in India. There are three main sections, one each for EV traction motors, power electronics and software. The project team met with many stakeholders, particularly several firms in the value chain to obtain relevant data and insights. This exercise was challenging due to three factors, i.e., commercial concerns, criticism consciousness and company considerations. These are briefly described below to provide a perspective into challenges faced during this deep dive.

First, there is a strong commercial concern in the private sector to share information, particularly data. This is natural and expected in most industries. However, it was particularly heightened in this case due to the evolving nature of the technology and a rapidly changing market. Some of the companies politely, but firmly refused to meet; others were reluctant to share relevant information. A few came forth willingly and in detail, but that set was limited. Work arounds were adopted, such as to consult industry experts who retired recently or those who moved into consulting roles, but previously were in the industry.

Second, criticism consciousness, particularly towards the government, meant general reluctance to talk freely about their experience with respect to policies and schemes such as the PLI. The project team therefore proposed NDAs wherever required and conducted the regional workshops under the Chatham House rules.

Third, company considerations such as internal policies also created barriers. Many companies bar their executives from discussing even industry level themes with external stakeholders and an explicit permission is often required. In some cases, senior executives noted that they will participate only if there was a specific government order requiring them to engage. These considerations meant that professional judgement had to be used in some instances and adopting a more tedious and longer process in other cases.

4.1 Traction motors

4.1.1 Overview and Key Suppliers

The market is dominated by 2W and 3W segments, given the significantly higher demand and relatively simpler technology in these segments. Most of the motors manufactured in India are of BLDC (Brushless Direct Current) and PMSM (Permanent Magnet Synchronous Motor) type (discussed in more detail in the next sub-section). Typical motor type and ratings for different segments are presented in Figure 4.1.

Figure 4.1: Typical motor type and rating across EVs

Segment	Motor Type	Voltage	Continuous Power output
E2W	BLDC (IPM)	48 V	1.2 kW
E2W	PMSM	72 V	3.3 kW
E3W (Cargo)	BLDC	72V	8 kW
E3W (Passenger)	AC Induction	72 V	4 kW
E Car	PMSM	540V	106.4 kW
E Bus	PMSM	400/800V	145 kW
ELCV	PMSM	330V	30 kW
E Truck	PMSM	400/800V	145 kW

Source: RTI analysis


Component Localization
Localized Parts
Motor Casting Parts
Inverter Housing & Covers
Copper Bus Bar Machined Part & Rubber parts
Reducer
Stator
Rotor
Source: RTI

A large number of suppliers, comprising established players as well as start-ups are manufacturing various types of motors. Many of the established motor manufacturers produce more than 1 lakh units annually. Players like Anand Mando, Dana TM4, Sona Comstar, Varroc, TATA Prestolite and Lucas TVS are producing high volumes, while many new players are yet to start production.

While most suppliers (80%+) cater to 2W and 3W segment, a smaller set (30%) caters to 4W segment. Very few (10%) cater to bus and truck segments. Dana TM4, Bosch, TACO Prestolite Electric, Cell Propulsion are manufacturing traction motors for heavy EVs with Dana TM4 being the dominant player, capturing highest share of the heavy motor market. A detailed analysis of suppliers, products, volumes, and customers is presented in Figure 4.2. Start-ups are entering this market and differentiating their offerings based on technological innovation or E/E (Electrical and Electronics) expertise. Several start-ups including Chara, Physics Motor Technology, Entuple E mobility etc. are focussed on developing switched reluctance motors (SRM) as they do not need rare earth elements, cost less, and have a higher operating range, particularly for temperature. However, they experience torque ripple, which can generate noise and produce jerks. Start-ups interviewed by RTI concurred that this is a challenge but can be solved through motor control algorithms.

Figure 4.2: Traction EV motors manufactured in India

Large Companies

Company / Customers	Motor Type: BLDC	PMSM	ACIM	SRM	Motor power (kW): 2W	3W	4W	Bus/ Truck
Bosch India Bajaj Auto, TVS MotoCorp	●	●			<5		50-300	
Mahle India Ather, CNH, SDF, CAT, aftermarket	●		●		4 – 18		<250	
Dana TM4 Virya Mobility, Kinetic Green, OHM, Ultraviolette Automotive, JCB, Ashok Leyland, Tata Motors, JBM, Volvo Eicher, PMI. Exports: Zapp, Toro, John Deere, Navistar, JLG, Takauchi Annual volumes: 1,65,000 LV motors, 10,000 HV motors and inverters	●	●	●	●	3 – 35			160 – 540
Varroc* Bajaj Auto, Honda Annual volumes: 2,00,000 motors		●			3 – 6.5			
Uno Minda*	●				<2	6.5		

Mid-size Companies

<table>
<tr><th rowspan="2"></th><th colspan="4">Motor Type</th><th colspan="4">Motor power (kW)</th></tr>
<tr><th>BLDC</th><th>PMSM</th><th>ACIM</th><th>SRM</th><th>2W</th><th>3W</th><th>4W</th><th>Bus/ Truck</th></tr>
<tr><td colspan="9">Customers</td></tr>
<tr><td>Lucas TVS
Atul auto, Kinetic Green, KPT, Omega Seiki, Revolt, Lohia, Star, Shigan EV, Reep, e-Trio
Annual volumes: 60,000 (phase 1), extend to 120,000 (phase 2)</td><td>●</td><td>●</td><td></td><td></td><td colspan="2">1 – 7</td><td></td><td></td></tr>
<tr><td>TACO Prestolite Electric
Tata Motors, TVS Motor
Annual volumes: 1,80,000 units</td><td></td><td>●</td><td></td><td></td><td colspan="4">1.5 – 250</td></tr>
<tr><td>Napino Auto & electronics
Hero MotoCorp, Honda, Suzuki, Ola Electric, Ampere, and Ather
Annual volumes: Plan to manufacture 6,00,000 motors from FY 25</td><td>●</td><td></td><td></td><td></td><td colspan="2">1 – 5</td><td></td><td></td></tr>
<tr><td>Seg Automotive
OLA, Greaves, Piaggio, Bajaj</td><td></td><td>●</td><td></td><td></td><td>5</td><td>8</td><td></td><td></td></tr>
<tr><td>Medha Servo Drives</td><td></td><td>●</td><td></td><td></td><td></td><td></td><td></td><td><260</td></tr>
<tr><td>Shriram Pistons & Rings Limited (EMFI)
RunR mobility
Annual volumes: 1,44,000 motors</td><td>●</td><td>●</td><td></td><td>●</td><td colspan="2"><2</td><td></td><td></td></tr>
<tr><td>Sona Comstar
Tata Motors, Renault Nissan, FIAT, Ashok Leyland
Annual volumes: 4,00,000</td><td>●</td><td>●</td><td></td><td></td><td colspan="2">3 – 16</td><td>15</td><td></td></tr>
<tr><td>Valeo
Mahindra and Mahindra, Tata Motors, Omega Seiki Mobility</td><td></td><td>●</td><td></td><td></td><td></td><td></td><td><25</td><td></td></tr>
<tr><td>Shakti Pumps</td><td>●</td><td>●</td><td></td><td></td><td></td><td>1 – 1.2</td><td></td><td></td></tr>
</table>

Small Companies

<table>
<tr><th rowspan="2"></th><th colspan="4">Motor Type</th><th colspan="4">Motor power (kW)</th></tr>
<tr><th>BLDC</th><th>PMSM</th><th>ACIM</th><th>SRM</th><th>2W</th><th>3W</th><th>4W</th><th>Bus/ Truck</th></tr>
<tr><td colspan="5">Customers</td><td colspan="4"></td></tr>
<tr><td>Cell propulsion pvt ltd
Flipkart, BigBasket, and Bounce</td><td>●</td><td>●</td><td></td><td></td><td></td><td></td><td colspan="2"><50</td></tr>
<tr><td>Bhorzvan Motors pvt ltd</td><td>●</td><td>●</td><td></td><td>●</td><td colspan="2"><5</td><td><250</td><td></td></tr>
<tr><td>Elecnovo Pvt ltd
Annual volumes: 100,000 motor & controller (expected in 2024)</td><td>●</td><td>●</td><td></td><td>●</td><td colspan="2"><5</td><td><10</td><td></td></tr>
<tr><td>Arago Electric pvt ltd</td><td></td><td></td><td>●</td><td>●</td><td colspan="2"><2.5</td><td></td><td></td></tr>
<tr><td>Electra EV
Tata Motors
Annual volumes: 30,000 units</td><td></td><td>●</td><td>●</td><td></td><td></td><td></td><td colspan="2">5 – 180</td></tr>
<tr><td>Virya Mobility
Tata Motors, Mahindra
Annual volumes: About 40,000 motor and controller</td><td>●</td><td>●</td><td></td><td></td><td></td><td colspan="2">1 – 20</td><td></td></tr>
<tr><td>Konmos Technologies</td><td></td><td>●</td><td></td><td></td><td colspan="3">3.2 – 14</td><td></td></tr>
<tr><td>Rotomotive</td><td>●</td><td>●</td><td>●</td><td></td><td colspan="2"><5</td><td></td><td></td></tr>
<tr><td>Compage Automotion
Escorts Kubota, Sonalika (ITL), Autonxt, ACE</td><td>●</td><td>●</td><td></td><td></td><td colspan="2">0.4 – 2</td><td>15</td><td></td></tr>
<tr><td>Abhinava Rizel*</td><td></td><td></td><td></td><td>●</td><td>3 – 25</td><td>5 – 25</td><td>50 – 150</td><td>150 – 300</td></tr>
<tr><td>Entuple e-mobility
Annual volumes: 5,00,000 Motor & controllers (expected)</td><td>●</td><td>●</td><td></td><td>●</td><td>0.45 – 2.5</td><td>2.8 – 10</td><td colspan="2">30 – 155</td></tr>
</table>

Small Companies

Company (Customers; Annual volumes)	BLDC	PMSM	ACIM	SRM	2W	3W	4W	Bus/ Truck
Tsuyo Manufacturing Tata Motors, Maruti Suzuki Annual volumes: 60,000 (phase 1), plans to expand to 2,40,000	●	●	●	●	1 – 4	1.5 – 3	4 – 12	
Anand Mando Ola, Okinawa, Mahindra, Lectrix, Joy E-bike, Quantum, Okaya, Benling, Ather Annual volumes: 4,00,000 hub-motors & controllers and 1,20,000 mid-drive motors & controllers	●	●			<10			
Weber Powertrain Hero Electric and Okinawa Annual volumes: 3,00,000 motors and controllers	●				1 – 3.5			
Chara Bounce Annual volumes: 24,000 planned (2024), setting up plant of 5,00,000 capacity				●	6.5			
Star Engg Hero electric, Piaggio, Bajaj, Ampere, Atul Auto, Bounce Annual volumes: 1,20,000 controllers	●				<5			
Physics motor technology	●	●		●	<5			

Company size is based on annual turnover (Large: >5000cr; Mid-size: 500-5000cr; Small: <500cr)

** Working on PMSynRm motor technology*

Source: ICA & IESA (2023), RTI Analysis - Compiled using news articles and company annual reports.

4.1.2 Types of Traction Motors

Figure 4.3 presents the major types of traction motors used in EVs – Brushless DC (BLDC), Permanent magnet synchronous motors (PMSM), Switched Reluctance motors (SRM) and Alternate Current Induction motors (ACIM). Each of these have relative advantages and disadvantages in terms of efficiency, reliability, controllability, and cost.

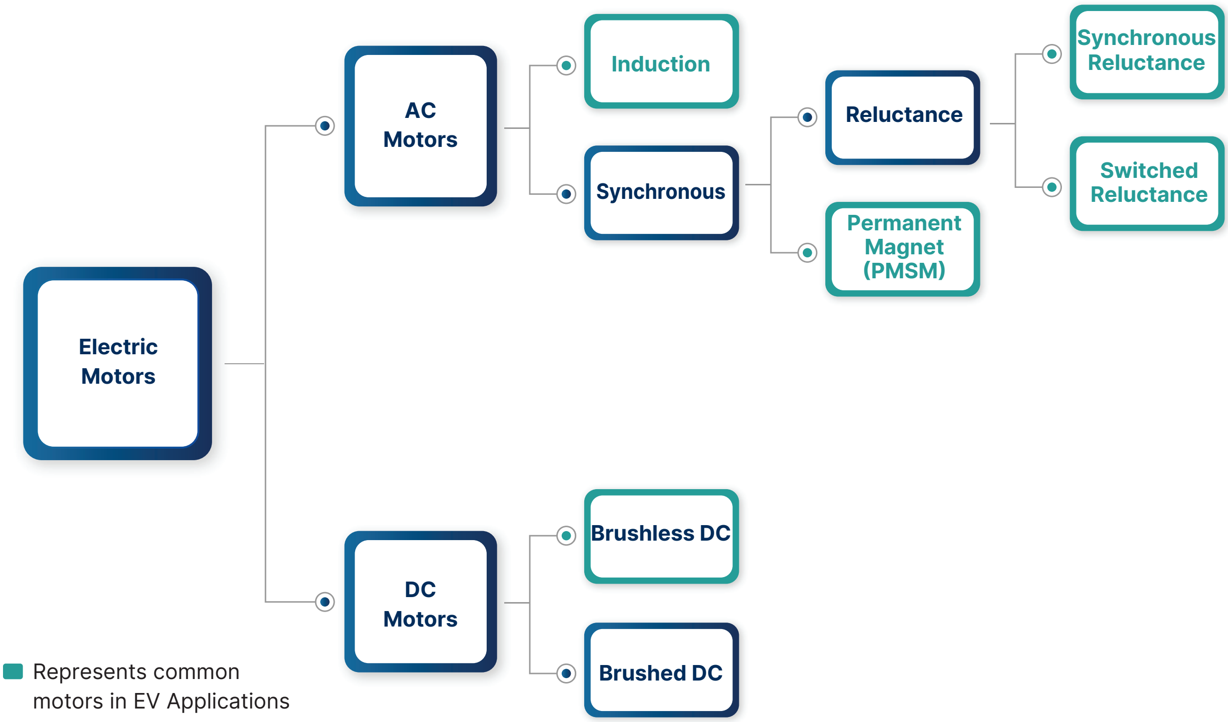
The choice of motor for a particular application depends on the power requirement and the type of vehicle. A heavier vehicle requires a more powerful motor compared to light weight vehicles. Further, the motor size impacts the weight, dimensions, and cost of the finished product.

While smaller motors tend to increase efficiency and range, they may not be able to provide sufficient torque. Hence, the size of the motor must be optimised to meet the specific needs of a particular product. BLDC and PMSM are compact motors with high power density. They are also highly efficient, but their manufacturing cost is relatively higher. On the other hand, AC Induction and SRM motors are relatively less compact and have lower efficiency. They are however cheaper than BLDC or PMSM, are robust and require low maintenance. Detailed comparison of technical characteristics and comparative analysis is presented in Figure 4.4.

4.1.3 Technology Trends in Traction Motors

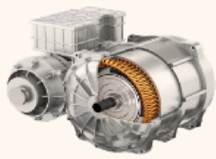
BLDC and PMSM motors are widely used for EVs in India. BLDC motors are used in smaller vehicles, particularly lightweight 2Ws (electric scooters and electric motorcycles). In case of 3Ws, they were used in earlier models. However, they are being phased out gradually due to overheating, particularly during high load conductions leading to stalling.

Figure 4.3: Types of traction motors used in EVs



Source: AutomoationForum.co (2021), Shimin, et al. (2016)

Figure 4.4: Comparison of different types of traction motors

Attribute	BLDC	PMSM	AC Induction	SRM
				
Power Density (kW/kg)	High	Very High	Medium	Medium
Efficiency	85-90%	90-95%	75-80%	75-95%
Starting Torque	Very High	Very High	Very low	Medium-High
Permanent magnet	Yes	Yes	No	No
Cost	Moderate	High	Low	Low- moderate
Segments	2W, 3W	4W, Bus, Trucks	3W, 4W, LCV, Bus	2W,4W
Placement in EV	Hub motors/ Mid drive motors	Axle	Axle	Axle
Advantages	Longer life span, less maintenance, high power to weight ratio, compact, simple construction.	High power density, high torque density, longer life span, less maintenance.	Low-cost motors, low maintenance, robust.	Simple to design and repair. Typically, no magnets, windings, or brushes. Can operate in harsher conditions.
Disadvantages	Sensitive to overheating. More expensive compared to brushed DC due to permanent magnets.	Complex control systems, high cost due to permanent magnets.	Lower efficiency compared to PM or BLDC motors.	Difficult to control, generates noise, electromagnetic interference.

Note: Both BLDC and PMSM represent the same motor topology. Image credits: Indiamart,tlabs
Source: ICA & IESA (2023); TIFAC (2018)

PMSM motors are generally used for E-cars, buses, and trucks, due to better efficiency, high torque, and compactness. AC induction motors are also used in a few cases for commercial vehicles. A detailed compilation of type of motors used in current E-models of buses and trucks is in Figure 4.5 & 4.6.

BLDC and PMSM motors are expensive owing to use of permanent magnets containing rare earth elements (REE). These magnets are typically made up of Neodymium-Iron-Boron (NdFeB) and generate the motor's magnetic field. India currently imports all REE based magnets as there is no domestic production.

The industry has initiated work to develop motors that do not require REE. The first step in this direction is the reduction of REE content in magnets by using alternative materials and reducing the grain size of the magnets to nanoscale with advanced magnet production technologies.

Use of ferrite magnets that do not require REEs is another possible solution. Alternatively, use of magnet free motors like switched reluctance motors (SRM) and synchronous reluctance motors (SynRM) is being explored by some of the motor manufacturers like Chara. Both these options reduce the motor cost substantially. However, their efficiency and power density (kW/kg) are lower compared to PM motors (Figure 4.7).

To bridge this gap in efficiency between PMSM and SynRM, many variants of synchronous motors are under research and development, with and without magnets. Magnet assisted synchronous reluctance motor (PMSynRM) is a hybrid of PMSM and SynRM that offers high torque density and power (Epaddock, 2022). Globally, players like Tesla use it in their products. Indian players such as Abhinava Rizel and Varroc are also working on this technology. Rizel Automotive recently announced launch of production of such motors for the E3W segment.

Figure 4.5: Motors for commercial vehicles

Heavy commercial vehicles in India run at low-speeds and require high torque to haul heavy loads. Motors that provide high torque at low speeds are therefore ideal for medium and heavy-duty applications. In small trucks and pickups, PMSM motors are dominant due to their efficiency and compact size, higher manoeuvrability and shorter ranges.

In medium duty trucks, both PMSM and AC induction motors are used, with PMSM preferred for better performance and long-range deliveries.

Induction motors achieve peak efficiency at higher speeds and low-torque conditions, which limits its usage for freight vehicles. Similarly, the efficiency and torque/power density of the SRM are not equivalent to that of the PM motors. Also, this technology is yet to be applied in the commercial EV market. Thus, both induction motors and SRMs may not be 'ideal solutions' for medium and heavy-duty electric trucks (MD/HDT) based on current technological evolution.

PMSM is widely used by OEMs producing commercial vehicles. PMSM can be classified as surface (SPM) or interior (IPM) machines. This classification depends on the placement of permanent magnets, either inside or on the surface of the rotor. IPM machines offer better mechanical robustness, overload capability and high torque density. These operate at maximum efficiency in the low-speed high-torque range, making it a suitable choice for the MD/HDT powertrain.

Source: Madichetty, et al. (2022)

Figure 4.6: Traction motors used in E-Bus and E-truck models in India

E Bus Models	GVW (kg)	Motor Type
TATA Ultra 9/9 Electric Bus	10200	Integrated Motor Generator
PMI Electro Mobility Urban	-	PMSM Motor
Ashok Leyland Circuit Electric Bus	-	PMSM Motor
Volvo 8400 hybrid electric bus	12900	PMSM Motor
E Truck Models	**GVW (kg)**	**Motor**
TATA Ace EV	1840	AC Induction motor
OSM M1KA 1.0	2620	PMSM
OSM M1KA 3.0	5000	PMSM
TATA ULTRA T.7 Electric Truck	7490	AC Induction motor
TATA Ultra E.9 truck	9000	3 phase PMSM motor
Ashok Leyland BOSS 1218 HB EV Truck	11990	-
Olectra Meghaetron Electric Tipper	28000	PMSM
TATA Prima E.28k Tipper	28000	PMSM
Tresa Motors V0.1	55000	Axial Flux PMSM
IPLT RHINO 5536	55000	PMSM

Source: RTI compilation from respective company websites

Figure 4.7: Power density comparison of PMSM and SRM motors

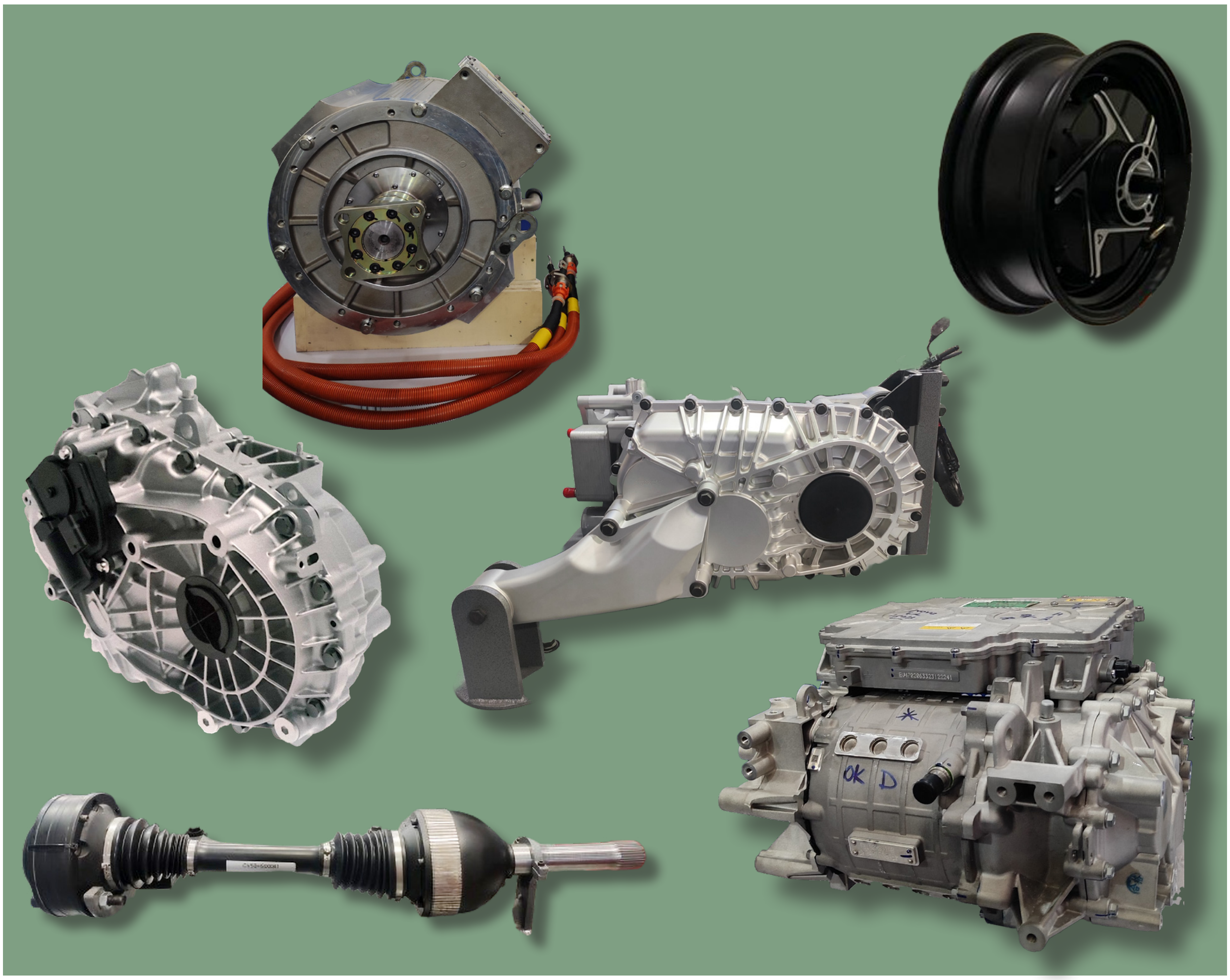
Type of motor	Power density (kW/kg)
PM BLDC *	2.32
PM Variable speed *	2
PMSM **	2
SRM **	1.8
Wound rotor synchronous motor **	1

*Source: * - B Sudha et al (2020); ** - Edmondson (2022)*

Externally excited Synchronous motors (EESM) is a magnet-free variant of synchronous motors, which is being developed by global players such as ZF, Mahle, Renault etc. ZF' I2SM (In-rotor Inductive Excited Synchronous Motor) transmits the energy for the magnetic field via an inductive exciter inside the rotor shaft (ZF, 2023). This is an ultra-compact design, with high power and torque density, resulting in performance at par with PMSM as per the company claims. Similarly, Mahle has developed a Magnet-free Contactless Transmitter (MCT) which is a type of externally excited synchronous motor. In this design, the magnetic field required for operation is generated contactlessly through induction by exciter coils in the rotor. With its compact design and scalability, it can be used across vehicle segment, from small cars to heavy commercial vehicles (Mahle, 2024). These motors are new to the Indian market and their adoption will depend on cost-performance matrix.

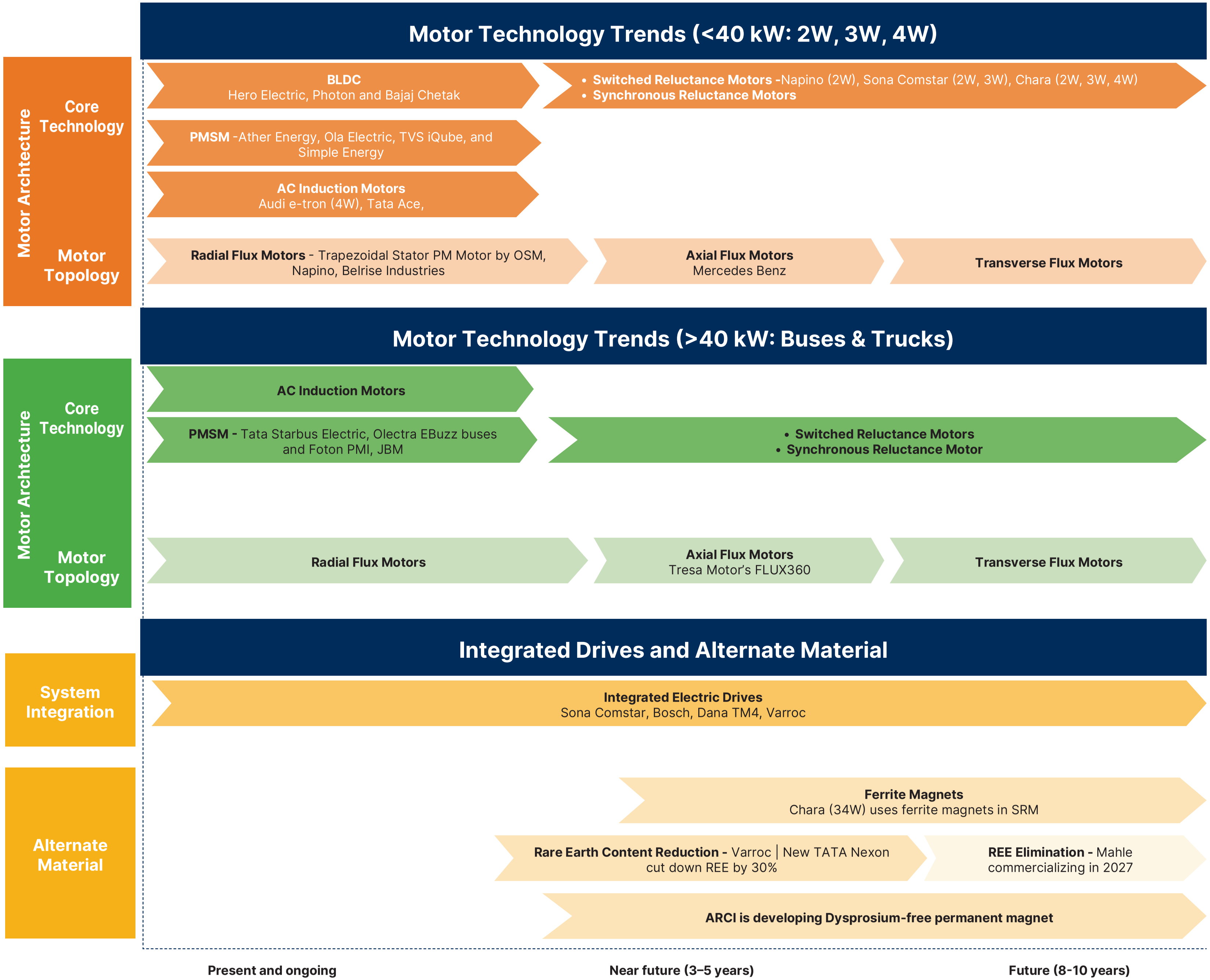
R&D in motors is directed towards finding ways to make magnet-free motors and improving efficiency so that motors with reduced REE content perform at same level as PMSM. The current and future EV motor trends are indicated in Figure 4.8 and 4.9.

Rapid technological evolution is evident in motors, particularly relating to magnetic field flows. Currently, radial flux motors dominate the market. However, axial flux permanent magnet motors (AFMs) are gaining traction due to several advantages. Tresa Motors (Indian electric truck OEM) and Mercedes-Benz are developing models with AFMs as they offer a higher power-to-weight ratio. Additionally, their design allows easier integration with transmission systems, leading to a compact powertrain and hence suitable for electric vehicles.



Source: RTI compilation from visit to Bharat Mobility Expo Delhi, 2024

Figure 4.8: Technology trends in traction motors



Source: RTI Analysis

Figure 4.9: Additive manufacturing

3D printing or additive manufacturing (AM) is an emerging manufacturing technique which does not require a block of material or a mold to manufacture physical objects. It is 'additive' in the sense where 3D objects are made from a digital file using an additive process, created by stacking layers of material. It is being explored by EV motor manufacturers to fabricate motors. AM enables rapid prototyping, as the parts are made layer by layer in additive flow, and can be produced in hours as opposed to weeks, thus significantly reducing the time to market. At the same time, there is no requirement of expensive dies and molds in AM. They can also address the barrier of complex shapes for certain kinds of motors (e.g SynRM). Complex 3D geometries as a result of AM techniques can enable optimization of space for thermal management of motors.

While this technology is gaining prominence, it is at a very nascent stage and is not yet adopted by EV component manufacturers in India. The reasons for its low adoption include its high initial cost, inability to produce large single parts, challenges in supporting different materials for printing one single component (Massimiliano Gobbi, 2023). As the market for EVs develop, AM is expected to be adopted for thermal management of motors.

Source: Gobbi, et al. (2023)

Emergence of Transverse Flux Motors (TFM) is also noted. TFMs have higher efficiency and a compact design, making them suitable for direct drive applications that require high torque at low speeds. Both AFMs and TFMs have more complex structures as compared to traditional radial flux motors.

Integrated drives combining motor, inverter, and gear box, known as 'e-Axles' are becoming the industry standard. Dana TM4, Schaeffler, ZF, Sona Comstar, Bosch etc., amongst others, have introduced e-Axles. The electric motor, power electronics and transmission are combined in an integrated unit making the drive compact, simple and efficient by reducing the number of connectors and cables required.

Further efforts to reduce size and improve efficiency of e-Axles are also underway with R&D focused on 2nd and 3rd generation of e-Axle technology. In addition to compactness and better efficiency, OEMs are also utilising this as an opportunity to enhance comfort and safety. Compact size will enable vehicles with almost flat floor, lower centre of gravity and reduce risk of engine block thrashing cabin in an event of accident. Manufacturers also see e-Axles as an enabler of sustainability and resource conservation, as they start to focus on circularity and carbon neutrality.

4.1.4 Composition of EV motors

Motors consist of a rotating component (rotor) and a stationary component (stator). Typically, stators consist of electrical steel stack with copper windings used to generate an electromagnetic field. Rotor material differs depending on technology i.e., PM motors contain magnets in rotor, induction rotors have copper or aluminium bars, wound rotor motor may have more copper windings, while reluctance motors are mainly composed of steel (IDTechEx, 2024). Housing is generally made of aluminium. Composition (by weight) of various motor technologies is presented in Figure 4.10.

Motors constitute a significant part of the total cost in a typical commercial EV. In a BLDC motor, about 40% of the cost is constituted by the permanent magnet. Cores of a motor (stator and rotor) makes about 26% of the cost and housing accounts for 16% of the cost. Stator windings made of copper form 8% of the total motor cost (Figure 4.11).

Figure 4.10: EV traction motor composition (by weight) across technologies

	PMSM	Induction Motor	SynRM	PMSynRM
Electrical Steel	45%	47.5%	47.5%	47%
Copper	10%	8.5%	9%	8.8%
Aluminium	34%	17%	17%	17%
Other steel	8%	13%	13%	13%
Magnet	3%	0%	0%	0.95%
Others such as Non-Conductive	<1%	14%	13.5%	13.4%

Source: Nordelöf, et al. (2018) Rassõlkina, et al (2020)

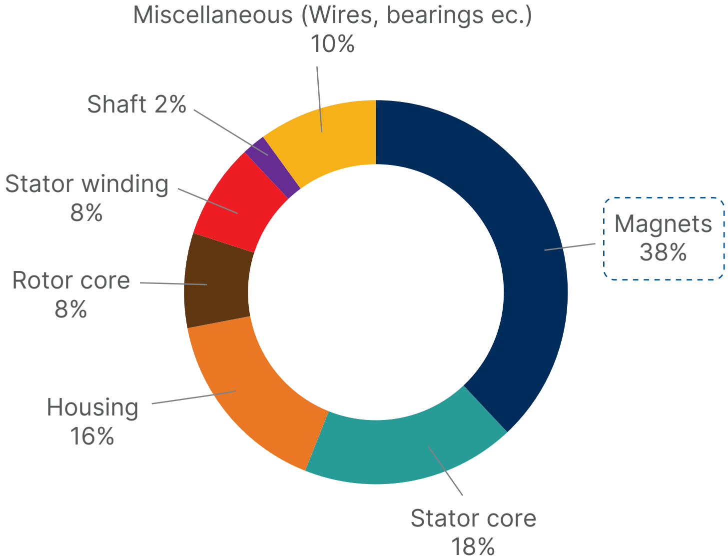
For PMSM, the stator core and its winding are the most cost-intensive part of the motor. This is due to the complex machinery required for the winding and quantity and prices of copper. Magnet assembly (rotor) is the second most expensive part. The housing and cooling system production are relatively small in comparison to the other parts (Hemsen, et al., 2023).

In the non-magnetic motors like induction motors or reluctance motors, the steel cores (stator and rotor) have the largest share of about 50%, followed by copper windings and housing, contributing approximately 23% and 14% respectively (Rassõlkina, et al., 2020). The cost of traction motors can be reduced by replacing copper windings with aluminium ones (Roush Industries Inc, 2022).

4.1.5 Value Chain of Traction Motors

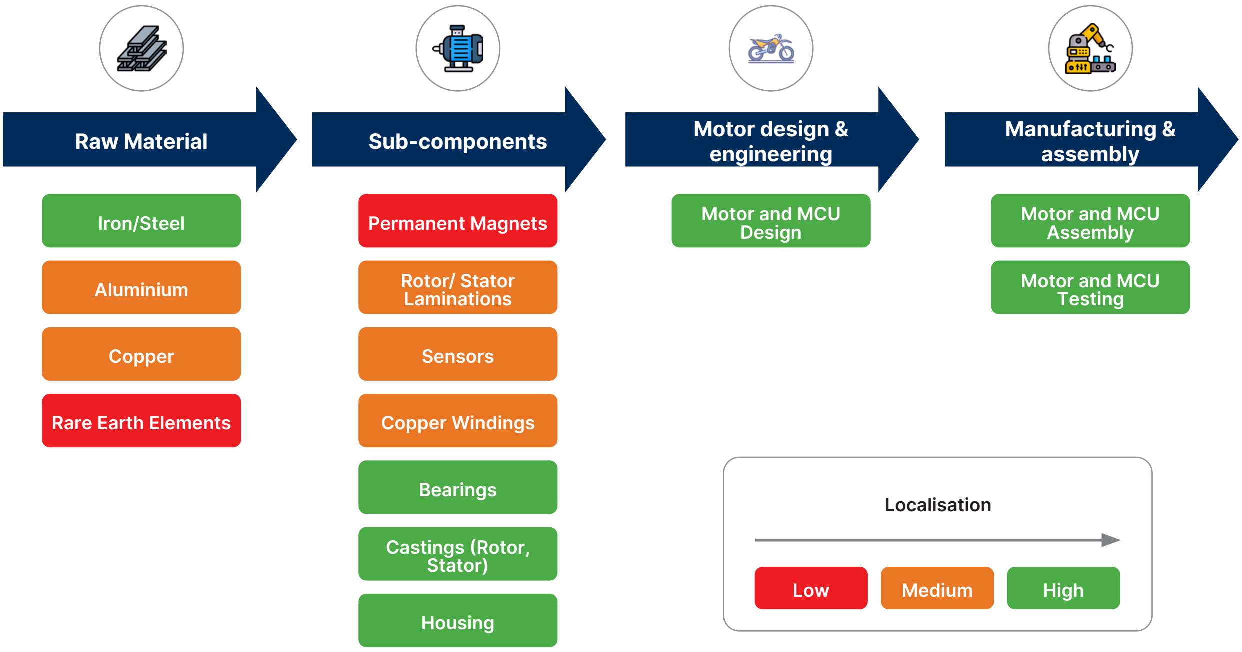
The upstream elements include raw material mining, i.e., for magnets (iron, neodymium, dysprosium and praseodymium depending on type), windings (copper) and other parts (steel, aluminum). Manufacturing of traction motors includes the following activities (Figure 4.12):

Figure 4.11: Cost composition of BLDC motor (32 kW)



Source: RTI Analysis, Primary consultations with Industry

Figure 4.12: Traction motor value chain



Source: RTI Analysis

1. Designing the motor and controller based on vehicle requirements.
2. Sourcing sub-components like permanent magnets, stator laminations, copper windings etc.
3. Machining and assembling.
4. Integrating motor and controller, and testing.

Motors are typically bundled with controllers and provided as an integrated offering. Motor controllers regulate the flow of electric current to the motor to control the speed and torque generated. It is a combination of power electronics (MosFETs (Metal-Oxide-Semiconductor Field-Effect Transistor), hall effect sensors, Gate driver ICs), motor control algorithm and firmware.

The value chain for traction motors in India is localised to reasonable extent, especially for 2/3W segments. Parts like stators, rotors, shafts, and casings are predominantly being produced by Tier 1 players while bearings, castings, copper windings and stamped laminations are sourced from Tier-2 suppliers. However, in India, traditional copper wire windings are usually produced , though hairpin windings are preferred in high performance electric motors. Since hairpin windings require specialised manufacturing techniques and equipment, they are more expensive to produce. Among large manufacturers, ZF has invested heavily in the hairpin windings technology (ZF, 2024).

Several industry players affirmed that the scale of motor production for an EV traction motor manufacturer should be about 1,00,000 motors annually (for 2/3Ws). Most of the established players are already producing at this scale as mentioned. However, startups may not have this scale and therefore, opt for contract manufacturing or tie ups with other manufacturing partners for mass production as explained in the box item (Figure 4.13).

In the initial years, most of the EV motors were imported. However, with increasing sales, market evolution and localisation push, suppliers have developed indigenous products and started to compete with differentiated offerings. Customisation of parameters suited to local weather and driving conditions provides flexibility,

Figure 4.13: Contract manufacturing for EV components

It refers to a business model where a company outsources the manufacturing processes to third party that has the expertise, equipment, and resources to produce the contracted goods according to the specifications provided. Contract manufacturing is preferred for specialised components such as batteries and motors that require large volumes to be cost effective due to large upfront investment required.

Benefits:

- Savings on upfront investment required to set up own manufacturing facility.
- Contract manufacturer realises economies of scale.
- Enables focus on core competencies like design, engineering, R&D etc.
- Risk mitigation, particularly of technology obsolescence and fixed investment.

Examples:

1. Specialised motor designing startups like Chara and Quanteon Powertrain outsource traction motors manufacturing.
2. Altigreen owns the design of motor and controller but outsources manufacturing.

Source: RTI Analysis

which is typically not possible with imported motors or the reverse engineering route.

The need to develop specialised motors suitable to India's market, has encouraged entry of startups which specialise in motor design e.g., Chara, Quanteon, Elecnovo, Entuple etc. Established firms tie up with motor design firms or form Joint Ventures with foreign players to access technical know-how, R&D, while manufacturing and assembling in-house. A few examples of such tie ups and joint ventures are provided in Figure 4.14.

> *"We are investing energy and time to develop EV motors, which usually take about 3 years for development, testing, and trials. Rather than reverse engineer imported motors, we are keen on partnerships for exchange of technological expertise, resources, and solutions. This will help us modify and develop market-driven products suited for local and customer needs."*
>
> ***-A Leading EV traction motor manufacturer in one-on-one meeting with RTI team***

Motor design and manufacturing startups have acquired deep domain expertise in simulation, power electronics and related areas. They have also recruited trained experts from structural and material sciences domains and multi-physics analysis. Few startups also cited that license fee for some simulation tools is significant and may cost more than Rs. 1 Cr. However, they are procuring and investing in them to develop differentiated products.

Some level of vertical integration is also noted in the traction motor segment. For example, OEMs such as Ola, Hero Electric, Ashok Leyland are planning to manufacture EV traction motors to maintain control over supply chain and gain competitive advantage.

Figure 4.14: Examples of JVs and acquisitions in the EV powertrain segment

Name of firm	Partner	Nature of partnership	Details
Sona Comstar	Equipmake (UK)	Commercial licensing agreement	Licensing agreement for manufacture and sale of drive motors, inverters, and drive trains in the power range of 100kW to 440 kW for electric cars, buses, commercial vehicles, and off-road vehicles. Equipmake will provide the validated design of the products and Sona Comstar has exclusive rights to manufacture and sell these products in certain agreed territories. One-time fee for each motor and variable royalty payment will be paid to Equipmake.
Napino	EVR (Israel)	Commercial licensing agreement	Commercial licensing agreement for acquiring EVR's lightweight, compact design Trapezoidal Stator Radial Flux PM motor topology.
Dana	TM4 (Canada)	Acquisition	Dana's acquisition of TM4's motor, inverter, and control systems capabilities.
Kalyani powertrain	Harbinger Motors (US)	JV	JV for manufacturing electric drive trains for commercial vehicles.
Shriram Pistons & Rings Ltd	EMFI Innovations (Singapore)	Acquisition	Shriram Pistons' acquisition of a majority stake in EMFI to gain technical know-how and expertise in motors and controllers manufacturing and expand presence in electric 2W, 3W, cars, CVs, and buses.

Source: Company websites

The aspects of value chain where there is significant import dependence and limited domestic capability are briefly described in the sub-sections below.

a) Copper

Amongst other applications such as in the electricity industry for wires and transformers, copper is also used extensively in stator and rotor windings. EV's also require higher quantity of copper in other parts as well. EV motors contain significant quantities of copper, depending on the motor size and power rating (Friedrichs, 2023). Figure 4.15 depicts copper intensity across different types of traction motors. As shown below, AC Induction motors have the highest copper content among other motors.

Copper is one of the 30 critical minerals listed by the Government of India due to its high economic importance and high supply chain risk. India is not self-sufficient in copper because of low reserves (Ministry of Mines, 2024) therefore, copper concentrates are imported as raw material and converted into refined copper. Copper produced in the country is able to meet the domestic demand partially, while the rest of the requirement is imported (Figure 4.16).

India's copper ore imports have increased significantly in value terms over the last three years due to increasing demand from various sectors. Total value of imports increased to INR 26,000 Cr in FY 24, recording a CAGR of 21%% over FY19, (Figure 4.17). About 10% of India's annual copper demand (Economic Times, 2022), amounting to 1.5 Million tonnes in FY23 (ICAI, 2024) is used by the automotive sector. This is poised to grow further to 1.7 Million tonnes by FY27, with increasing EV penetration as one of the key drivers (Hindustan Copper Limited (HCL), 2023).

Figure 4.15: Copper content in EV traction motors

Attribute	Switched Reluctance	PM Synchronous Reluctance	PMSM	Induction motor
Average copper kg per kW (cars)	Data NA	0.04	0.09	0.16

Source: International Copper Association, ICA (2020)

A shift towards motors with reduced or without magnet such as induction motors or synchronous motors is likely to further increase copper demand. Some offset is possible through improvements in efficiency as demonstrated by manufacturers such as Schaeffler & BorgWarner (IDTechEx, 2024). Nevertheless, copper demand and imports may remain significant in the foreseeable future.

b) Permanent Magnets and Rare Earth Elements

The two most popular magnets used in EV motors are Neodymium-Iron-Boron (NdFeB) and Samarium–Cobalt (SmCo). These magnets contain a mix of rare earth elements (REEs) such as Neodymium, Praseodymium, Dysprosium, Terbium (used as an alternative to dysprosium), and Samarium, depending on the end use. REEs constitute the largest portion of the magnet cost.

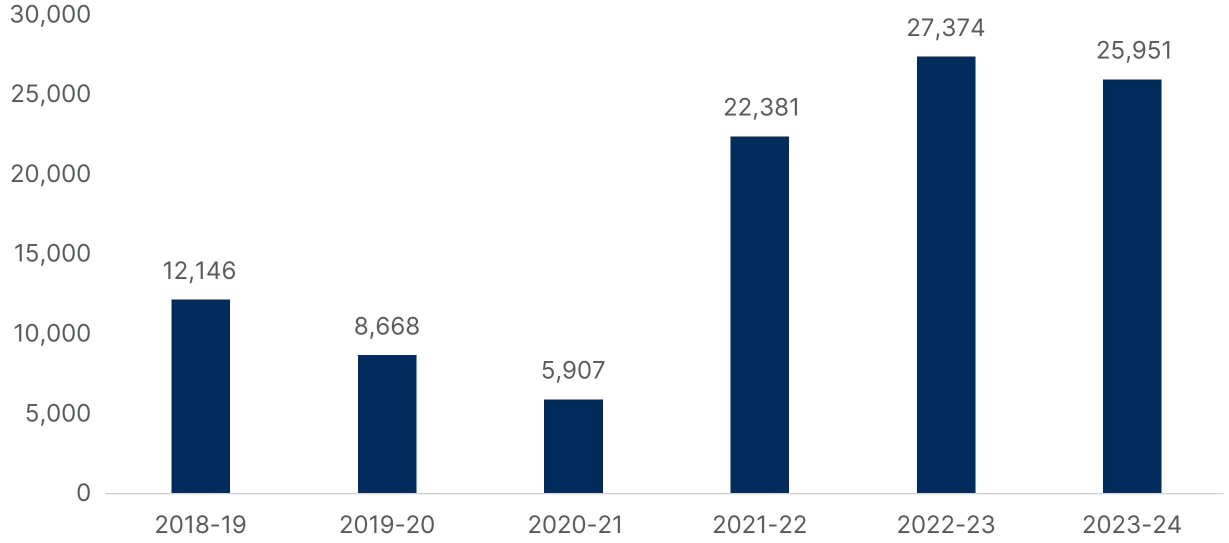
China holds about 34% of the global REE reserves while India holds about 5% of total global reserves. India's rare earths ecosystem is focused on mining and refining rare earth oxides, which are exported to other countries for further processing. IREL (India) Limited and Toyutsu Rare Earths India Pvt Ltd. (TREI) are few companies engaged in upstream (mining) and some mid-stream activities (separation and purification of rare earths). However, the downstream segment including industrial scale facilities to form alloys and produce magnets etc. is non-existent (PIB, 2023) (Figure 4.18).

Figure 4.16: India copper demand and supply scenario

Parameter	Quantity (MT) (FY 23)	Quantity (%)
Supply side		
Production	5,55,000	57%
Imports	4,21,078	43%
Total	**9,76,078**	**100%**
Demand Side		
Exports	71,252	7%
Domestic consumption	9,04,826	93%
Total	**9,76,078**	**100%**

Source: MCX (2024)

Figure 4.17: India's total import of copper ore and concentrates (INR Crores)



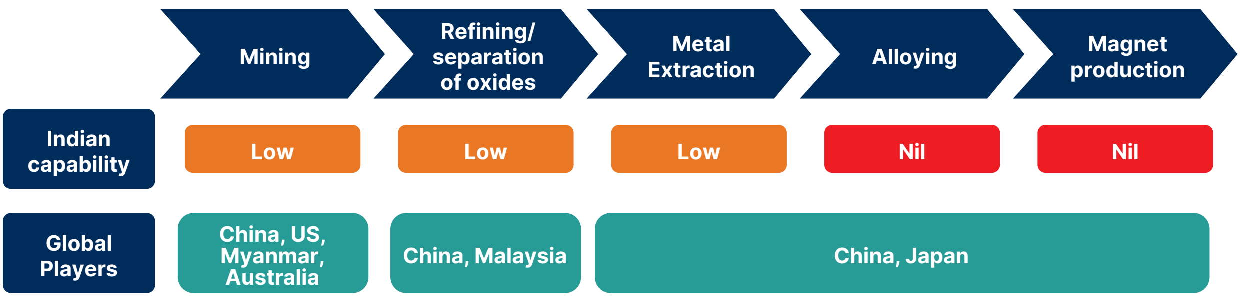
Source: Ministry of Commerce, Export Import Bank (HSN Code:26030000)

India is thus dependent on imports for commercial use permanent magnets. In terms of value, India imported 77% of its permanent magnet supply from China, followed by Hong Kong (6%), Singapore (2%), Indonesia (2%) and others in 2023-24 as presented in Figure 4.19.

Currently, few Indian companies produce REE magnets. These include Compage Automation Systems Private Limited and Mark Elektriks that manufacture rare earth magnets for BLDC motors and PMSM. Those companies produce small-sized magnets for finished goods, either by procuring RE magnets from foreign players and machining them into the desired size, or by importing metal powder and use powder metallurgy process known as sintering, to produce magnets (DST, 2024). However, recent developments suggest gradual progress towards REE magnet production.

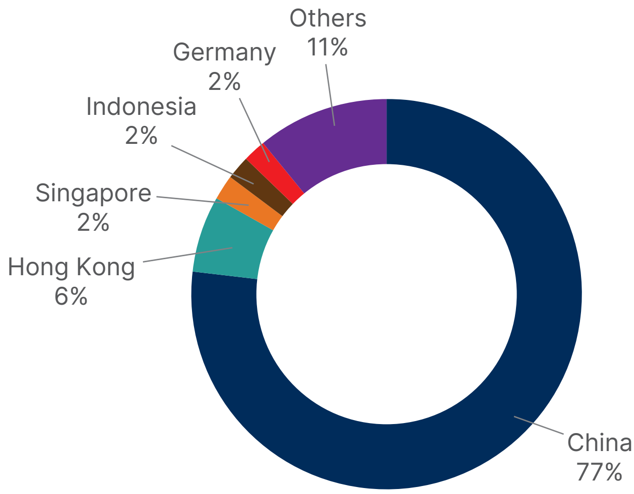
- **Launch of rare earth exploration license blocks by states:** Rajasthan announced the auction of three blocks of rare earth elements, rare earth metals and potash minerals in March 2024 (PIB, 2024). This will likely increase domestic availability of raw materials.
- **Industry collaboration:** Permanent Magnet Limited (PML) is a leading domestic player in the magnet industry. It has signed an MOU with Quadrant International, US for exploring the possibility of a JV in manufacturing of Neodymium Magnets and assemblies in India

Figure 4.18: Value Chain of permanent magnets



Source: Permanent Magnets Limited (2023); Rizos, et al. (2022)

Figure 4.19: Country share in India's permanent magnet imports (FY 2023-24)



Source: Ministry of Commerce, Export Import Data bank

(BSE, 2023). Through the JV, PML plans to venture into mid-stream value chain by buying processed raw material for further refinement and processing and manufacturing magnets.

- **Ongoing research in magnet production processes:** International Advanced Research Centre for Powder Metallurgy & New Materials (ARCI) recently developed a new method to create high-performance REE magnets without using Dysprosium[3] (PIB, 2022).
- **International partnerships for critical minerals:** Government of India has initiated steps to secure the REE supply chain. It identified 30 critical minerals and opened exploration and mining operations for private sector which will enable use of its mineral reserves for clean energy transition. Simultaneously, by participating in initiatives like the Mineral Security Partnership (MSP) and bilateral agreements with countries such as Australia, India aims to further enhance its position in critical mineral exploration, development, processing, and trade. Under the India-Australia partnership, battery minerals have been identified to be sourced from Australia to begin with, and detailed due diligence is underway for five projects (2 Lithium and 3 Cobalt). Opportunities also exist for collaboration on research, development, and business opportunities in rare earths. These are detailed in Figure 4.20.

c) *Electrical Steel Laminations*

For motors that require high torque and power density, ultra-thin laminations made of cold rolled non-grain oriented electrical steel (CRNO)[4] are used. Electrical steel has high magnetic flux density and produces high efficiency. It also reduces overheating that causes difficulties during operation. India imports most of its electrical steel from other countries to meet demand for various sectors including EV motors and other industrial applications.

In case of EV motors, ultra-thin laminations of thickness below 0.35 mm are preferred. Thinner laminations reduce core losses and are thus preferred. In FY24, India imported (net of exports) approximately 0.2 Million tonnes of electrical steel (< 3mm thickness) valued at INR 1587 Cr (Figure 4.21 and 4.22).

Maximum quantities were imported from Korea (55%) and Japan (41%). Electrical steel imports have witnessed an increasing trend and that will abate when domestic production expands significantly.

[3] *Dysprosium is a heavy and costly rare earth element added to permanent magnets to improve their resistance to demagnetisation.*

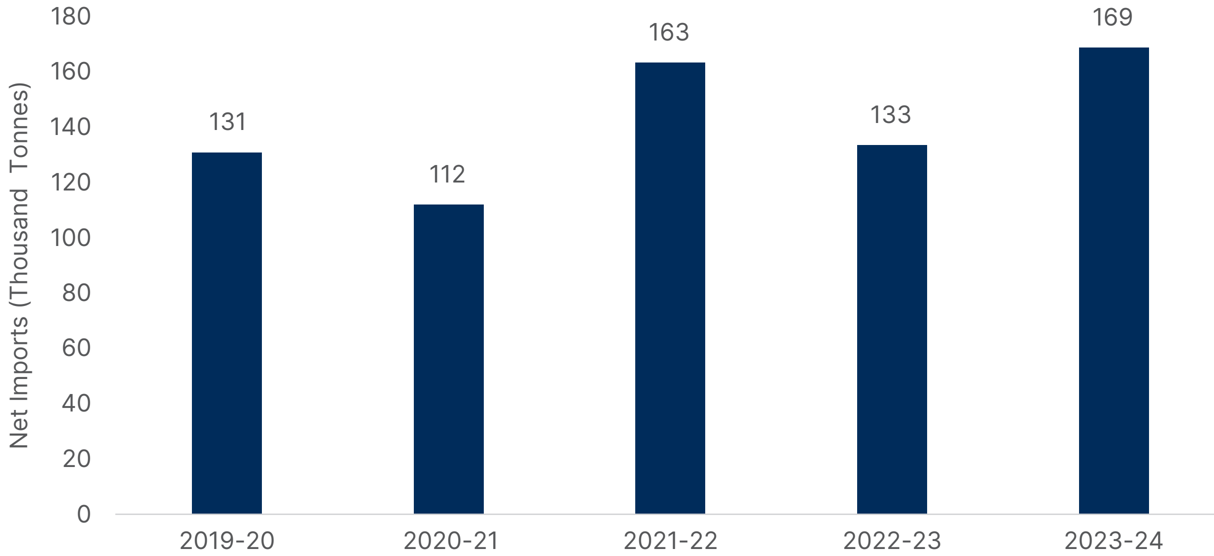
[4] *Grain oriented electrical steel may also be used for EV motors, but special measures have to be taken depending on properties of materials. Usually, CRNO is preferred for EV motors (Nippon Steel, 2019).*

Figure 4.20: Initiatives to strengthen supply of critical minerals in India

Initiative	Year	Engagement	Relevance
India-Australia Critical Minerals Investment Partnership	March 2023	International	Under the five-year MoU, there are opportunities to collaborate on critical and strategic minerals including REEs. The following key opportunities exist for REEs: - IREL and NMDC could explore strategic partnerships with Australian project owners, to invest in midstream processing of REEs. - Indian and Australian institutions could collaborate on R&D on REE exploration. - Indian companies can engage with Australian companies for offtake arrangements from advanced REE projects.
Joined the Mineral Security Partnership (MSP)	June 2023	International	US-led collaborative effort involving thirteen countries that aims to catalyse public and private investment in critical mineral supply chains globally. India is the only developing country in MSP. Under this initiative, MSP partners will identify opportunities and facilitate strategic interventions to advance critical minerals projects along the entire value chain, from mining, to processing, to recycling, both within and beyond MSP. This initiative will potentially enable Indian PSUs to acquire critical mineral assets abroad.
Identification of 30 critical minerals	July 2023	Domestic	GOI identified 30 minerals as 'critical' and launched the first-ever auction of these minerals by offering 20 blocks for sale to private sectors for geological exploration and immediate mining operations. Further, a Centre for Excellence for Critical Minerals (CECM) under the Ministry of Mines is also being proposed to be set up.

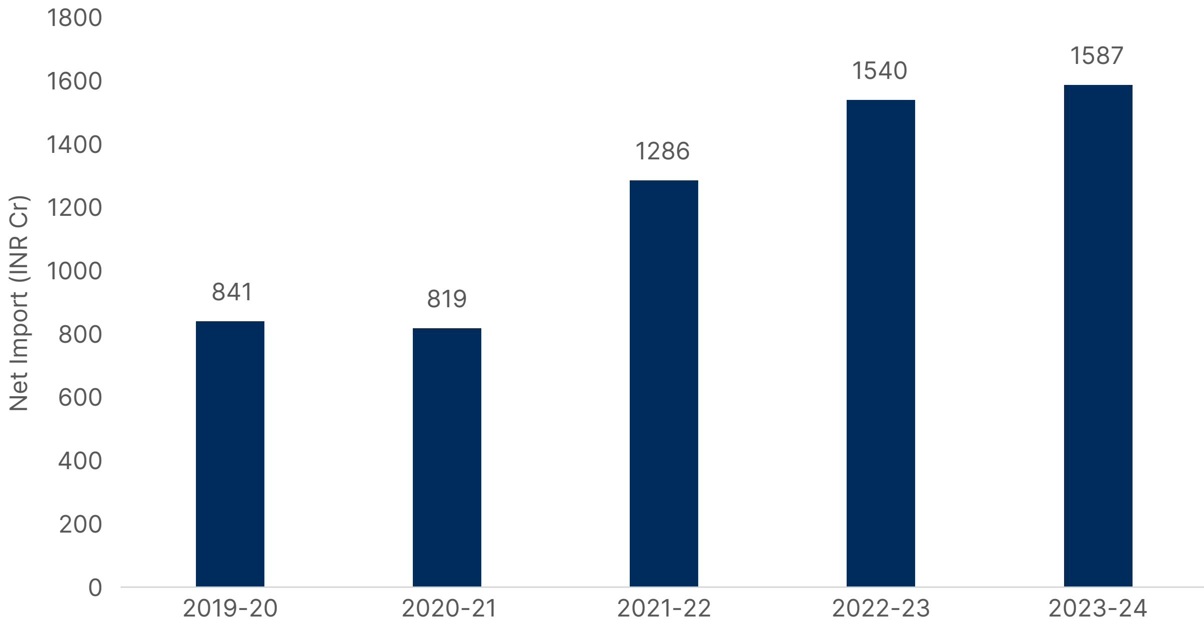
Source: PIB (2023), PIB (2023) Indian Express (2024), Commonwealth of Australia (2021)

Figure 4.21: India's cold-rolled electrical steel net imports, of less than 3mm thickness (000' Tonnes)



Source: Ministry of Commerce, Export Import data bank (HSN code: 72255010 and 72269210)

Figure 4.22: India's cold-rolled electrical steel net imports, of less than 3 mm thickness (in INR Cr)



Source: Ministry of Commerce, Export Import data bank (HSN Code: 72255010 and 72269210)

Electrical steel requires complex manufacturing process with high accuracy. In case of an error, the whole batch must be discarded (EE Power, 2023). Production of CRNO steel requires multiple processes at high temperatures, unique equipment, and high level of engineering and quality control. In India, a few companies such as SAIL and CSCI have ability to produce CRNO steel. SAIL has started commercial production of CRNO at the Silicon Steel Mill of its Rourkela Steel plant and produced 630 tonnes CRNO Coils in a single day (20th April 2024). China Steel Corporation India Pvt. Ltd. (CSCI) also has ability to produce electrical steel sheet in western coastal India with an annual production capacity of 200,000 metric tons. Both SAIL and CSCI can produce CRNO of various grades and thickness. Further, JSW recently commissioned a CRNO facility with 2,00,000 tonne per annum capacity at Vijayanagar steel complex in Karnataka.

d) Hall Effect Sensors

Hall effect sensors are used to detect various parameters such as position, speed etc. Hall effect sensors are relatively simple devices with high reliability. They measure magnetic fields without physically contacting the moving parts, minimizing wear and tear. Also, they have wide operating temperature range, important for EVs functioning in various climates.

In motors, they are used to detect the position of the rotor and the steering wheel and provide inputs to the motor controller, basis which the controller adjusts the amount of power supplied to the motor. Hall Effect sensors are also used to measure the current flowing into and out of the battery pack. This information is crucial for monitoring battery health, preventing overcharging or over-discharging, and optimizing battery management systems. EVs also utilize multiple Hall effect sensors for redundancy, providing a backup system in case of sensor failure.

These are also used in Anti-lock Braking Systems (ABS) of a vehicle to monitor wheel speed. Their inputs are used by the ABS controller to prevent wheel lockup during braking, ensuring vehicle stability and maintaining steering control. Similarly, in Traction Control Systems, these are used to detect wheel speed variations. TCS can then intervene by reducing engine power or applying selective braking to prevent wheel spin and maintain traction.

These are currently imported, mainly from China, Germany, and Japan. As per Ministry of Commerce's Export Import Data Bank (EIDB) data, hall sensors valued at INR 1600 Cr were imported in FY23.

4.1.6 Market Size

The current market size of EV traction motors and controllers for various EV segments is estimated to be INR 4200 Cr. It is expected to grow significantly by 2030 and is estimated to range from INR 60,000 to INR 152,000 Cr, in low growth or transformative scenario (Figure 4.23). E2Ws and E4Ws (cars) are expected to contribute maximum, approx. 90% of the motor and controller market. Annexure 4.2 describes the assumptions adopted for market sizing.

4.1.7 Localisation

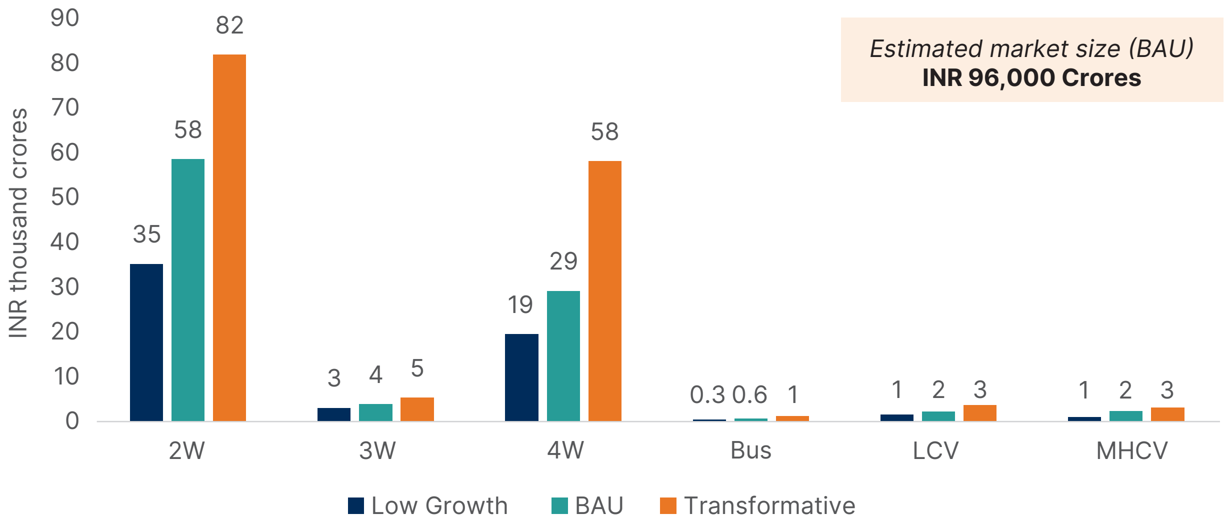
This analysis based on discussions with industry players and experts suggests that the average localisation level of traction motors and controllers for 2W and 3W segments is about 50%. Except certain components like permanent magnets for motors, electrical steel laminations, hall sensors used in motor controllers and semiconductors for controllers, all other sub-components are manufactured in India. For cars, buses and trucks, localization level is less than 20% in all cases (Figure 4.24).

Increasing localisation in EV motors will require several strategies and actions. One option is to develop local capabilities in design and manufacturing of magnets. It will require REE exploration, mining, and processing locally. An alternative is to manufacture REE free motors, a technology which is being explored by both established and new players, like Sona Comstar, Chara etc. The industry expects localisation levels to increase moving forward for all segments.

Further, localisation can be accelerated by identifying and targeting specific components/ sub-components that are relatively easier to manufacture locally. As per discussions with industry players and experts, components such as copper windings, thermal management, motor design, and sensors are easier to localise compared to other parts of EV powertrain. Targeted policies for such components would be effective.

Large motors for heavier vehicles are mostly imported. This is because motor manufacturing for heavy vehicles is complex and driven by technical requirements such as

Figure 4.23: EV Traction motor and controller market size 2030 (INR 000' Cr)



Source: RTI Analysis

Figure 4.24: Localization level in EV traction motors

Traction motors	Localisation (FY 23)*
2W, 3W	40% - 60%
Cars	0-20%
Buses and trucks	0-10%

Source: RTI analysis; Primary interactions with companies

high-power density, lower air gap, and noise, vibration, harshness (NVH) parameters. It requires precision manufacturing facilities and sophisticated tools for machining, joining, assembly etc. Since the market size is small, there is no dedicated production facility since it requires high investment in specialised equipment and tooling, including larger casting dies.

High investment makes it challenging for domestic manufacturers to compete with well-established overseas companies. Consequently, a few large players such as Dana TM4, Robert Bosch, Tata Prestolite, Kalyani Powertrain etc. are manufacturing large motors at present. In case of existing plants manufacturing smaller motors, significant upgrades and investment will be needed to produce larger traction motors and their controllers.

4.1.8 Circular Economy Strategies

India's pursuit of EVs is expected to drive the demand for new age minerals, including rare-earth elements (REEs). Given the current import dependence and expected demand growth, a long-term plan to address supply challenges needs to focus on circularity. The demand for four REEs, i.e., Neodymium, Praseodymium, Dysprosium, and Terbium, is likely to expand, as already discussed.

Motor and battery are the two major components where efforts towards circularity are evident. However, most recycling efforts currently focus on electric batteries. Technological developments targeting higher recovery rates enable the business economics of recycling batteries (McKinsey & Company, 2023). OEMs like Toyota are entering the practical application phase for all-solid-state batteries and bipolar structure batteries using inexpensive lithium iron phosphate (LFP), and are also developing square batteries, all with a focus on performance for the next generation of EVs (Toyota, 2023). The present study focuses on electric motors as batteries are not in the scope.

While the automobile industry needs to focus on circularity, it is also essential that other stakeholders in the ecosystem are aligned. For example, the insurance industry needs to understand and trust technical experts on safety and reusability of EVs and their components. Current evidence suggests that it is not the case. In US for example, some firms do not offer insurance to EVs. In other cases, insurers insist on complete replacement of key components, such as batteries, even for minor damages, citing safety concerns (Wired, 2023). These practices need to be reconsidered to enhance circularity.

4.1.9 Circular Strategies for Electric Motors

Electric motors constitute a significant part of the overall cost of an EV. Further, the design and manufacturing of electric motors utilises a variety of materials like cast iron, electrical and plain carbon steels, aluminium, copper, and rare-earth-based alloys for PMSM.

To analyse the potential of circular economy in EV traction motors, it is relevant to consider its three components, namely:

i. Casing, a one-piece casting, sealed by an endplate.

ii. Stator, which contains copper coil windings.

iii. Rotor with closed housing, which consists of a solid rotor shaft. Permanent magnets are glued together and mounted on this shaft.

Some of the circular economy strategies and a synthesis of ongoing efforts are presented below.

> *"There should be an proper standardization for all the EV players, so that it can also help in recycling process."*
>
> ***A Leading EV manufacturer during RTIs EV workshop***

a) Refuse and Reduce

The global supply of REEs is limited by the cost and complexity of exploring deposits and developing mines, including extraction and separation facilities. China is the largest REE producer in the world and accounted for 70% market share in 2022. India ranked 6th in global production, with about 1% market share (FICCI, 2023).

Global demand for REEs is however, projected to grow four to six times over the next few decades (Cho, 2023). Therefore, applying circular economy strategies to components that use REEs is critical from a sustainability as well as a financial perspective.

Because of the supply chain risks associated with REEs, many OEMs, components manufacturers, as well as various research institutes are working to develop electric motors that reduce the amount of REEs required in permanent magnets. For example, OEMs such as Toyota and Honda have reduced the use of more expensive REEs. Honda has replaced dysprosium and terbium and increased the amount of neodymium to maintain performance (TulaTech, 2022). Toyota has developed a magnet that halves the use of neodymium, and eliminated terbium and dysprosium from the process entirely, replacing them with lanthanum and cerium (Reuters, 2018).

Aside from reduction of REEs, efforts to eliminate their use by developing rare-earth free motors, and a move to replace PMSM and BLDC motors to reluctance and induction motors is also underway.

Some firms like Asea Brown Boveri (ABB), Chara Technologies, Vitesco Technologies, and Valeo, have been working on high-performance rare-earth free motors. ABB's synchronous reluctance motor (SynRM), and the ferrite-assisted synchronous reluctance motor (SynRM2), advances sustainable technology in efficiency and power density (ABB, 2016).

Chara Technologies has developed a rare-earth free motor for electric vehicles using aluminium, copper, and steel available within the country (Electric Motor Engineering, 2023). Vitesco Technologies has developed a new electric powertrain with rare-earth free, externally excited synchronous motor (EESM), which was considered more efficient than PMSM units, especially at high speeds (Electric Motor Engineering, 2023). Other automotive players like Valeo have also launched the development of a rare-earth free motor (Valeo, 2024).

Another strategy for reducing the use of rare-earth minerals is to deploy induction motors, which use electric current to create a magnetic field and power the motor. Though cheaper, these are less efficient and require a larger battery, thus reducing the driving range. To compensate for efficiency loss, automakers like BMW are redesigning drive units to reduce space and weight and increase inter-component efficiency (TulaTech, 2022).

These initiatives suggest progress, though many are in early stages. Use of REE-based motors is therefore likely to continue till some of these alternatives mature.

Reuse is the least researched circular strategy on account of lack of information about the condition of returned products. While reuse makes for an optimal circular strategy, few efforts have been made to establish the reuse of an electric motor as a whole. This is primarily because the sub-components maybe at different stages of wear-and-tear. Direct reuse would therefore require thorough testing and, if needed, repair.

The REASSERT project, an initiative funded by the EU and the German government, is one of the few initiatives which is focused on reuse as a CE strategy. It focusses on reusing, repairing, and remanufacturing traction motors. Under the project, a consortium led by Schaeffler is working to develop a prototype of an easy-to-disassemble electric motor (Schaeffler, 2024). This makes it possible to replace defective components and assemblies. The prototype will be easier to repair and encourage secondary reuse of the whole electric motor.

Among disassembled motor components, research has concentrated on reusing the permanent magnets of an electric motor. It involves disassembling the motor, extracting the permanent magnets, and re-fitting them in a new motor. The retrieved magnets could be repurposed for use in wind turbines, e-bikes, or other EVs, however, their cost-effective removal remains a challenge.

Under the EU-funded DEMETER Project, various research initiatives for designing and recycling electric motors were undertaken. Researchers at DEMETER, along with French global automotive supplier, Valeo, developed the world's first recyclable e-motor using recycled neodymium magnets that can be easily removed by sliding them out of the motor (CORDIS, 2019).

Given that reuse initiatives require further research and testing, it may be challenging for Indian companies to work in this area in the immediate future. However, it is worthwhile for the larger players to be informed of global efforts underway and to participate in pilot initiatives. This will make it possible to be aware of possible applications, business models, risks, and access global best practices.

c) Repair

Repair strategies for permanent magnet synchronous motors (PMSM) can be categorised into rectifying three types of faults, i.e., magnetic, electrical, and mechanical. When these faults occur, restoring the functionality is considered the optimal circular economy strategy.

i. **Mechanical fault:** Almost 40-50% of all motor failures are mechanical, which include the tearing of the bearing, or its false arrangement, leading to bearing faults. Replacing with new bearings restores the motor, and the old bearings, made of high-grade steel can be recycled (W.Thamke, et al., 2015).

ii. **Electrical fault:** About 35-40% motor failures relate to stator winding insulation and core, causing electrical faults. Replacement of the stator winding, made up of copper wire and insulation, fixes the motor. This process is similar regardless of the motor design, thus making it easy to scale. The old copper winding makes high-grade scrap and sent for recycling (AEMT, 2018).

iii. **Magnetic fault:** This fault is caused due to demagnetisation of the permanent magnets. A high operating temperature can permanently damage the magnet through coercive forces caused by opposing magnetic fields. Prevention, with more rigorous demagnetisation analysis, and tests to mitigate faults, are essential to guarantee performance, efficiency, and reliability of the PMSM.

Scheduled repair and maintenance can prolong the life of a motor by 2-3 times. It is an area that merits more research and innovation. India has a long tradition of repairing old motors and therefore, efforts in this direction should be encouraged.

Experience from outside India demonstrated the need to develop an ecosystem for circularity for it to be widely adopted. For example, in the UK, dearth of trained technicians to repair EVs is increasing repair costs. This is resulting in insurance companies writing-off EV cars even for small damages, sending the vehicles directly to the junkyards for dismantling (Bloomberg, 2024). Synetiq, a UK-based auto dismantler, claims to have a 55% increase last year in EV cars and vans for disposal (Synetiq, n.d.). Many of the EVs earmarked for disassembly or crushing in the UK are deemed fixable, albeit at a price (Bloomberg, 2024). Other countries like Germany, Sweden, and Norway are investing in improving EV competence skills so that the lack of trained mechanics is less notable. Thus, with better trained EV technicians and auto repair shops, 'repair' rather than 'replace' could become a viable proposition.

d) *Remanufacture*

Remanufacturing of EV components like battery, electric motor, power electronics, etc. is different from remanufacturing components for an ICE vehicle. Remanufacturing EV traction motors is still not established. Remanufacturing process for EVs, contrasted with its ICE counterparts, has been analysed in the Journal of Remanufacturing (Casper, 2021).

EVs adopt greater degree of software and electrical processes and therefore a defective part is often replaced with a new part. Addressing quality and reliability standards in EV remanufacturing therefore requires special test equipment and software to check the functionality. It requires specialised technical equipment as well as highly skilled professionals.

The recentness of the EV revolution is reflected in industry players still innovating and the lack of standardisation in traction motors. The lack of established protocols and standardisation of traction motors makes EV remanufacturing a challenging venture. In-house remanufacturing could be an area of interest for OEMs, especially as they retain control over quality and protection of intellectual property. This would help extending the life of their products and offer affordable options to customers.

Given the steady growth in EV-adoption, remanufacturing is an area that can provide first-mover advantage to early entrants.

e) *Recycle*

Recycling of materials requires significant energy and investment. It should be used when tighter loops of circular economy are not possible.

End-of-life (EoL) strategies currently focus on recycling methods like shredding, to reclaim REE and other valuable elements. Current technological limitations lead to loss of material quality, such that the extracted materials cannot be reused in motor applications. The global recycling rate for REE in motors is less than 3%, despite these materials constituting about 40% of the cost of a permanent magnet motor (EE Power, 2024).

Research initiatives like REASSERT are working on improving the value-retention strategies for obsolete motors. The project recycles raw materials from motors by disassembling them and sorting the individual materials before shredding. An artificial intelligence (AI) tool uses data from reference motors to analyse and select suitable strategies for retaining the value for a given application (PM Review, 2024).

Annexure 5 provides illustrative case studies focused on circularity and additional information on strategies that can be adopted by stakeholders in the value chain.

4.2 Power Electronics

Power electronics (PE) is a combination of components that control and optimise conversion of electrical power to mechanical energy to power the vehicle. Power electronics components constitute a significant portion of the total cost of an EV, of which more than a third is composed of IGBT (Insulated Gate Bipolar Transistor) and MOSFETs (Metal Oxide Semiconductor Field Effect Transistor). IGBT and MOSFETs are critical devices used to control current and switching, and to amplify electronic signals.

4.2.1 Power Electronics Components

A typical EV consists of three key devices – on board charger, DC-DC converter, and inverter. For E2W and E3Ws, components are offered separately, however for cars and buses, integrated products combining two or more components is typical (e.g., OBC+ DC-DC converters or OBC+ DC-DC converter + PDU (Power Distribution Unit)). Details of various components and offerings of different manufacturers are included in Figures 4.25 and 4.26 respectively.

4.2.2 Technology Trends

Most OEMs are increasingly looking to simplify vehicle design and assembly processes to reduce cost and weight. As a result, Tier I suppliers have assumed many of the design, engineering, research and development and assembly functions traditionally performed by vehicle manufacturers (Aptiv, 2022).

"Today, OEMs are coming to us to manufacture components for short-term contract duration of say two to three years. We are expected to make long-term investments for short-term contracts, while it is very likely that the OEM will start in-house production and my investment will be in vain."

A Leading EV component manufacturer in one-on-one meeting with RTI team

Source: RTI

Figure 4.25: Power electronics products mapped across segments

Component	E2W	E3W	E Cars	E buses & trucks
On board charger		✓		
DC-DC Converter	✓	✓		
Inverter	✓	✓	✓	✓
Integrated product (DC-DC converter + OBC combo)			✓	✓

Source: Company product listings, primary interaction with companies

Figure 4.26: Examples of Integrated Components

Component Manufacturer	Name of component	Integrated components	Segment
Valeo	High Voltage Power Box	DC-DC converter + OBC + PDU	4W
	Charger converter	DC-DC converter + OBC	4W, Bus
Tata Elxsi	Integrated Power Combo Unit (in the design phase)	DC-DC converter + OBC + PDU	4W
Denso		Inverter + DC-DC Converter	4W
Delphi	Combined Inverter and DC/DC Converter	Inverter + DC-DC Converter	4W
Bosch	Charger converter	OBC + DC-DC Converter	4W

Source: Company product listings

A key trend is the use of wide band gap (WBG) power electronics, such as gallium nitride (GaN) and SiC. WBG semiconductors can operate at higher frequencies and higher temperatures, which reduces the size and weight of the inverter and improves efficiency. This reduces the need for cooling and allows for more compact designs. The movement towards WBG devices will likely accelerate owing to migration to 800V electrical architecture (ultrafast charging) from current 400V (fast charging).

Silicon carbide-based semiconductors are at a nascent stage globally. Most EVs manufactured in India use Silicon chips, which cost less than Silicon carbide ones. Relative to Si-IGBT (Silicon-Insulated Gate Bipolar Transistor) modules, Silicon carbide based MoSFETs are 3-5 times more expensive. SiC inverter development is costly and time consuming and takes 2.5 -3.5 years of development time from concept to production. It also requires highly specialised skills and expertise in product development (Figures 4.27 and 4.28).

GaN inverters are providing a compelling alternative in vehicle architecture below 600 V and less than 100 kW (Ricardo, 2023).

Figure 4.27: Technology innovation trends

Technology innovation	Description	Examples
Wide band gap (WBG)* power electronics	WBG semiconductors, having band gap three times that of conventional silicon, can operate at higher frequencies and higher temperatures, which reduces the size and weight of the inverter and improves efficiency.	• Silicon carbide inverters developed by ZF, Bosch, Denso. • Tesla Model 3 was the first passenger car to utilise SiC inverter.
Integrated power modules	Integrated power modules combine the inverter, motor control, and other components into a single package. This reduces the size and weight of the inverter and improves reliability by reducing the number of connections and components.	• Integrated power electronics controller developed by Aptiv. • Integrated charger converter developed by Bosch.

** WBG have band gap three times that of conventional silicon*

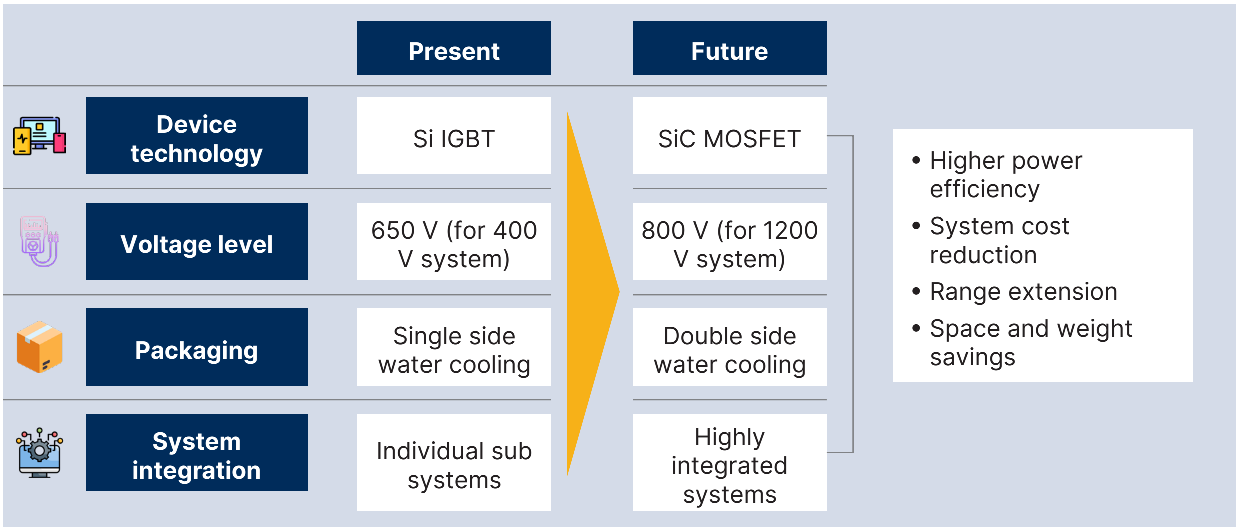
Source: Company websites of Embitel, Aptiv, and Bosch

Figure 4.28: Comparison of different semiconductor material characteristics

Material Property	Si	SiC-4H	GaN	Diamond
Band Gap (eV)	1.12	3.26	3.4	5.47
Breakdown Field (10^5 V/cm)	3	30	30	100
Electron Mobility (cm^2/Vs) (300 K)	1500	900	1250	1900-2300
Electron Saturation Velocity (10^7 cm/sec)	1	2.7	2.7	2.7
Thermal Conductivity (W/cm^2 K)	1.48	4.9	1.3	25

Source: (Nebel, 2023)

Figure 4.29: Technology trends for EV power electronics



Source: Frost & Sullivan (2022)

Despite this, it is expected that silicon-based semiconductors will be displaced by silicon carbide in inverters, DC-DC converters and on-board chargers due to high performance requirements particularly in heavy vehicles. Innovation in SiC will continue to focus on system weight and size reductions to achieve greater power density. Figure 4.29 summarises the key technology innovation trends in PE.

Source: RTI

4.2.3 Power Electronics Value chain

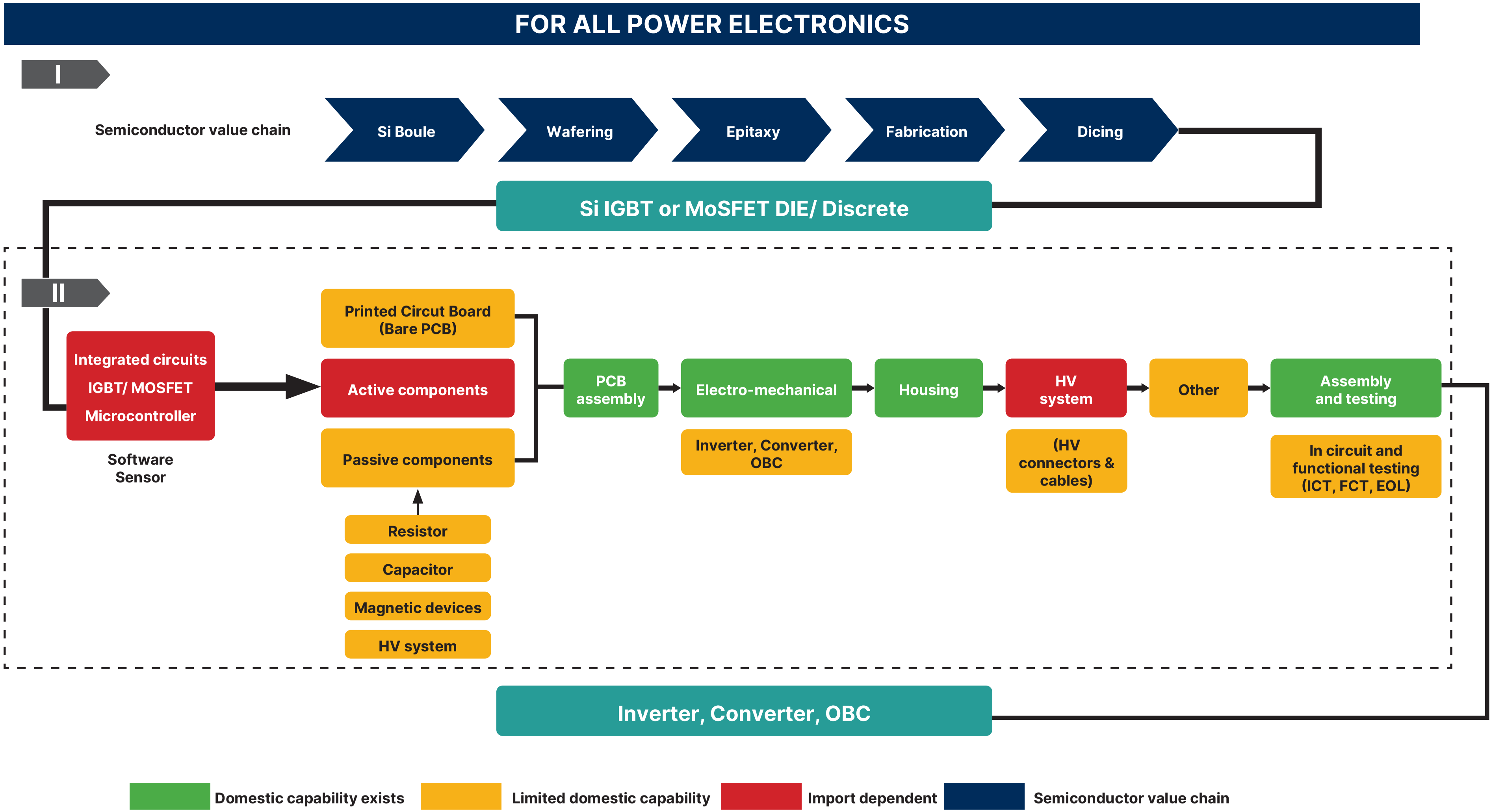
The value chain for power electronics components can be split into two parts. The first part relates to the upstream power semiconductors, where Silicon (Si) based discrete devices, or modules are developed (refer to Figure 4.30, lower half). The Si IGBTs (Insulated Gate Bipolar Transistor) and MOSFETs (Metal Oxide Semiconductor Field Effect Transistor) are critical devices that provide the ability to control current and operate at high switching frequencies. These components start life as a thin Si wafer which is 6 or 8 inches in diameter. Using an epitaxial layering process, materials are deposited on the base wafer to produce epitaxial wafers (or epi-wafer) that enables electronics to be fabricated onto their surface. The blocks of semiconductor material within the wafer (individual die) are separated and made into discrete devices or power modules which are then used to produce inverters. This involves several electrical, electronics, and mechanical assembly steps, adding further value to the product (Advanced Propulsion Centre UK, 2023).

The second part of the value chain relates to power electronics assembly, integration, and testing (refer to Figure 4.30, upper half). Indian component suppliers are concentrated in the second part of the value chain, where active and passive components, printed circuit boards (PCB) are imported and assembled in plants in India. Very few component manufacturers are sourcing PCBs from domestic players or manufacturing them in-house. As per industry inputs, this is mainly due to the low quality of domestically manufactured PCBs. Due to high investments, USD 10-15 Billion for fabrication and USD 5 Billion for assembly, testing, and packaging (ET Telecom, 2023), and the complex manufacturing processes, India does not have a semiconductor ecosystem for chip design, fabrication, assembly, test and packaging in this segment. However, investments are planned in fabs, assembly and testing facilities as several schemes have been announced over the last few years to build the semiconductor ecosystem in the country. Examples include PLI scheme for electronics, design-linked incentive scheme, Chip to Start-up or C2S, and SPECS all focused on development of the semiconductor ecosystem.

Three major firms including the Tata group announced investments of USD 18 Bn in chip manufacturing in 2024. Chips manufactured in India are expected to be rolled out by 2026 (Business Today, 2024). Figure 4.31 shows the semiconductor investments made in India.

Companies developing DC-DC converters are also producing chargers as these are similar in terms of technical know-how and capabilities. However, as evidenced in KII (Key Informant Interview) and expert interviews with RTI, only large and specialised component manufacturers are into building traction inverters for EVs. A table showcasing the key players in the Power electronics sector in India is provided in Figure 4.32.

Figure 4.30: Power electronics value chain



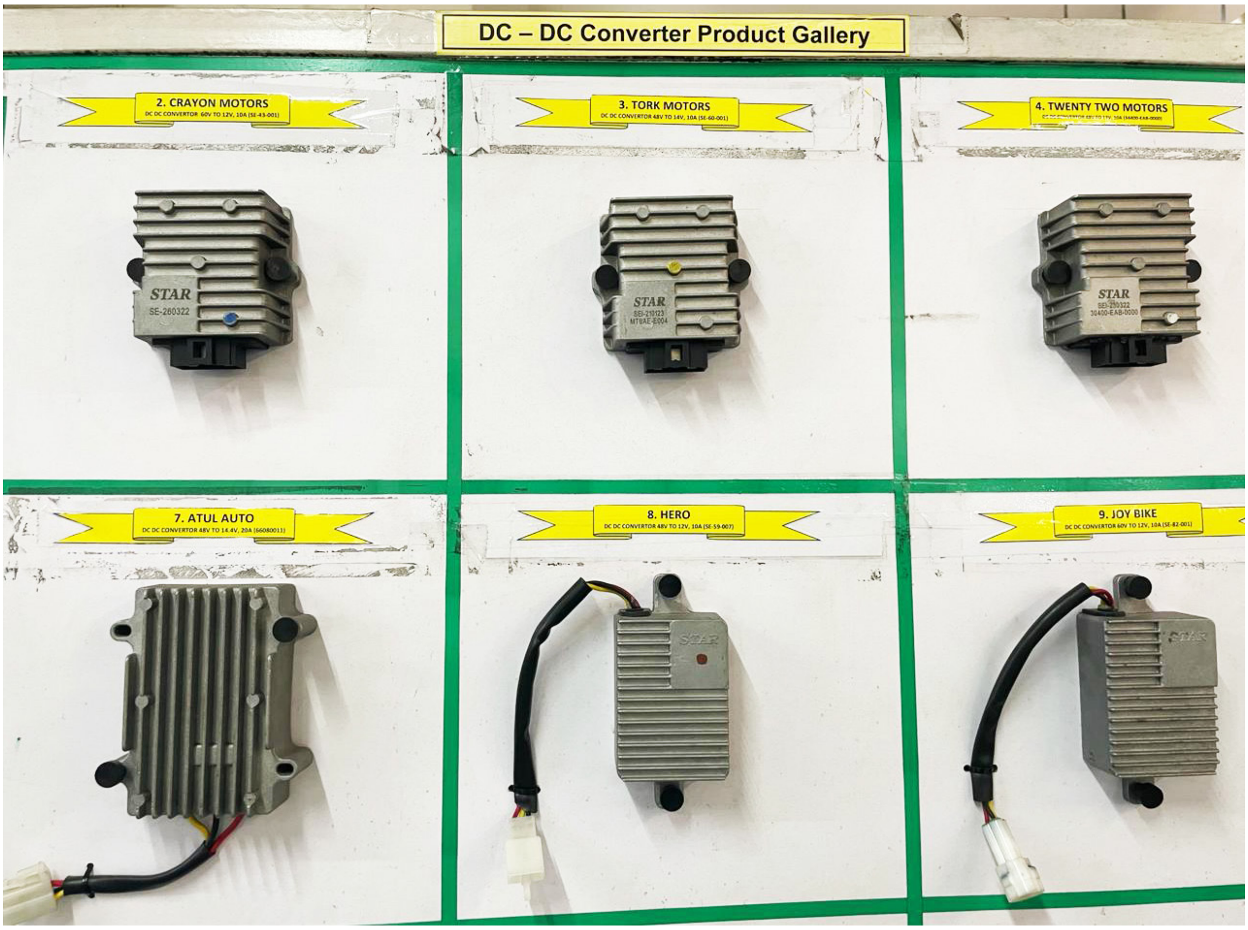
Note: Sensors can be active or passive component

Source: Adapted from Power electronics Value chain, Advanced Propulsion Centre UK (2023); ACMA (2021); Primary interactions with companies

Figure 4.31: Semiconductor investments in India

Firm name	Partner	Type	Year	Investment (INR Cr)	Location	Capacity
Micron Technology		ATMP	2023	22,500	Sanand, Gujarat	
Tata Electronics	Powerchip Semiconductor Manufacturing Corporation (Taiwan)	ATMP	2024	91,000	Dholera, Gujarat	50,000 wafers per month (3 Billion chips annually)
Tata Semiconductor assembly and Test Pvt Ltd (TSAT)		OSAT	2024	27,000	Morigaon, Assam	48 Million chips per day
CG Power	Renesas Electronics (Japan) & Stars Microelectronics (Thailand)	OSAT	2024	7,600	Sanand, Gujarat	15 Million chips per day
Total investments – INR 1.48 lakh Cr (USD 18 Billion)						

Source: RTI compilation from annual reports, company websites and articles in the Press



Source: RTI

Figure 4.32: List of power electronics manufacturers in India

Company	DC-DC converter	OBC	Traction Inverter	BMS
Denso	Yes (4 wheelers)		Yes (4 wheelers)	Yes (4 wheelers)
Lithion Power				Yes (2 wheelers, 3 wheelers)
Aptiv Components India (Delphi)	Yes (2 wheelers, 3 wheelers, 4 wheelers)	Yes	Yes	Yes
Yazaki India	Yes (4 wheelers)			Yes (4 wheelers)
Bosch	Yes (4 wheelers)	Yes (4 wheelers)	Yes (4 wheelers)	Yes (4 wheelers, trucks)
Virya Mobility	Yes (4 Wheelers)	Yes (2 wheelers, 4 wheelers)		
Electra EV		Yes (Trucks)		Yes (4 wheelers, Buses)
Napino	Yes (2 wheelers, 3 wheelers)	Yes (2 wheelers, 3 wheelers)		Yes (2 wheelers, 3 wheelers)
ABB India	Yes (Buses)	Yes (4 Wheelers, Trucks, Buses)	Yes (Trucks, Buses)	
Varroc	Yes (2 wheelers, 3 wheelers)	Yes (2 wheelers, 3 wheelers)	Yes (2 wheelers, 3 wheelers)	Yes (2 wheelers, 3 wheelers)
Valeo	Yes (3 Wheelers, 4 wheelers, Buses)	Yes (4 wheelers, Buses)	Yes (4 wheelers, Buses)	
IPEC		Yes (2 wheelers, 3 wheelers)		
Star Engg	Yes (2 wheelers, 3 wheelers)	Yes (2 wheelers, 3 wheelers)		
Kalyani Powertrain	Yes (Buses, Trucks)	Yes (Buses, Trucks)	Yes (2 wheelers, 3 wheelers, 4 wheelers)	Yes (2 wheelers, 3 wheelers, 4 wheelers)
Borgwarner	Yes (4 wheelers)	Yes (4 wheelers)	Yes (4 wheelers)	Yes (4 wheelers)
Uno Minda	Yes (2 wheelers, 3 wheelers)	Yes (2 wheelers, 3 wheelers)		Yes (2 wheelers, 3 wheelers)
Anand Mando	Yes (4 Wheelers)	Yes (2 wheelers, 3 wheelers)	Yes	
LivGuard	Yes			
Tata Autocomp	Yes (2 wheelers)	Yes	Yes	Yes (2 wheelers, 3 wheelers, Buses, Trucks)

Source: RTI Compilation

4.2.4 Cost Structure

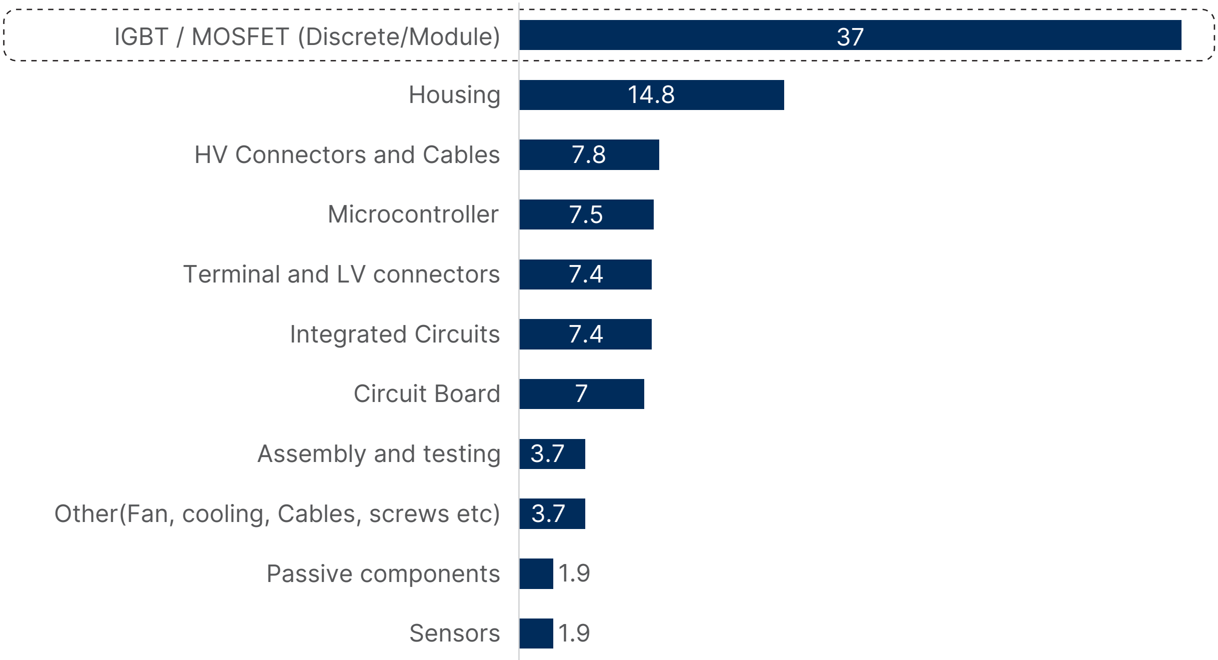
a) DC-DC converter

HV and LV connectors, microcontrollers, and integrated circuits, together account for over 30% of the share in the bill of materials of an HV DC- DC converter (Figure 4.33).

b) Inverter

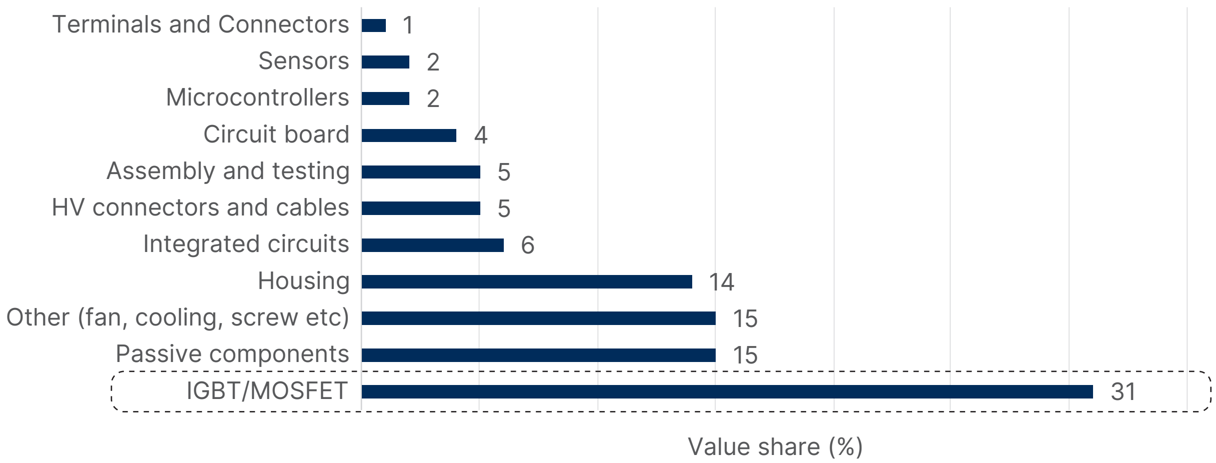
The bulk of the cost, about 40%, of an inverter is comprised of active components, including IGBTs/MosFETs with a detailed break-up provided in Figure 4.34. Localisation can be significantly increased by manufacturing IGBTs/ MoSFETs domestically. Domestic production of semiconductors is likely in the next few years given the investments planned in the semiconductor ecosystem.

Figure 4.33: Value share of subcomponents of HV DC-DC converter



Source: Industry inputs

Figure 4.34: Value proportions of subcomponents - Inverter



Source: Advanced Propulsion Centre, UK (2023)

4.2.5 Market Size

The market size for EV power electronics is expected to grow to INR 30,000 - INR 79,000 Cr in 2030 from INR 3500 Cr in 2023 under different scenarios as depicted in Figure 4.35. This represents an increase of 10 to 22 times over the current market. The highest growth is likely in the DC-DC converter and traction inverter segments for E2Ws, E3Ws and cars reflecting the growth in these segments (See Annexure 4.2 for details).

4.2.6 Imports and Localisation

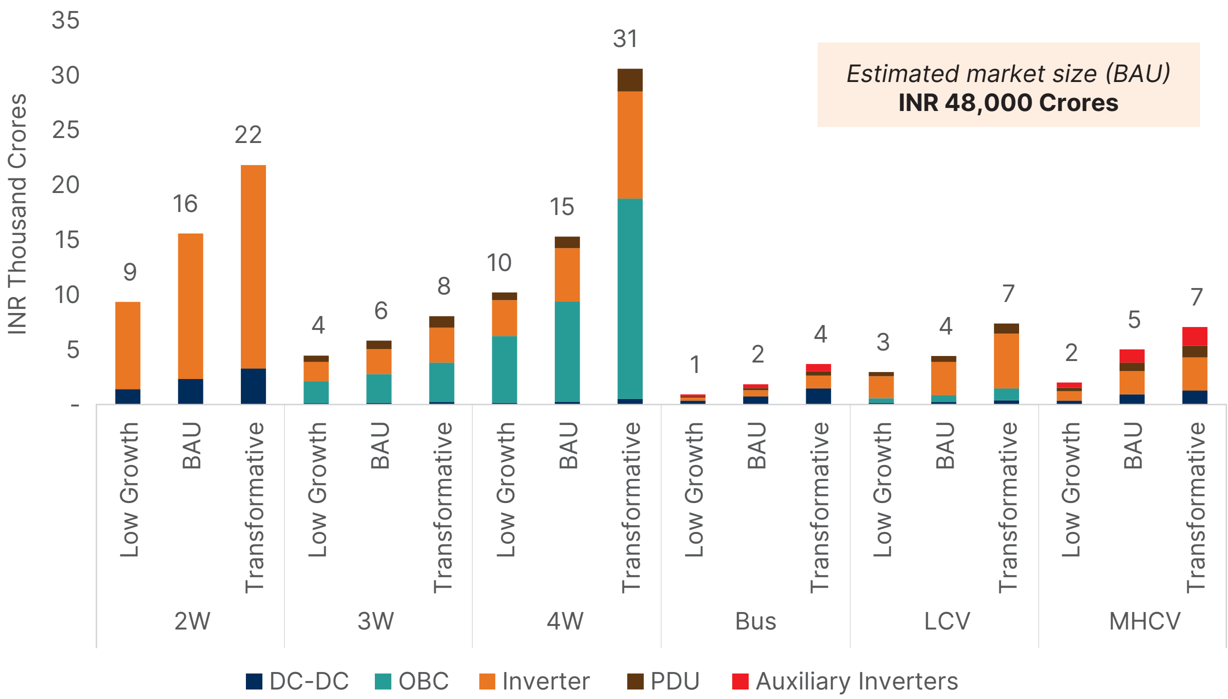
There is significant import dependence for EV power electronics components, specifically the active components like IGBT and MOSFET switches, which form the bulk of power electronics cost. Most active and passive components are made of semiconductors, which are entirely imported. On board chargers, cables, HV connectors are also largely imported.

There are domestic capabilities in certain segments such as PCB assembly, software and network integration, low voltage connectors and testing. PCBs are sourced from China and Hong Kong owing to low cost and better-quality (HillmanCurtis, 2022). Further, there is a lack of capabilities in the assembly of complex, multilayered and compact PCBs required for EVs. A large part (>90%) of the bare PCB demand is met through imports (EY, 2023). RTI's interactions with multiple manufacturers revealed that quality, cost, and speed are the three key reasons for import.

India's import of microcontrollers and MOSFETs have more than tripled in the last five years, while IGBT imports have become five times over the same duration (Figures 4.36 & 4.37). Imports are driven by increasing demand across sectors such as consumer products, industrial applications, EVs, amongst others. Majority of the imports of microcontrollers and PCBs are from China and Hong Kong, which expose suppliers to relatively higher supply chain risks.

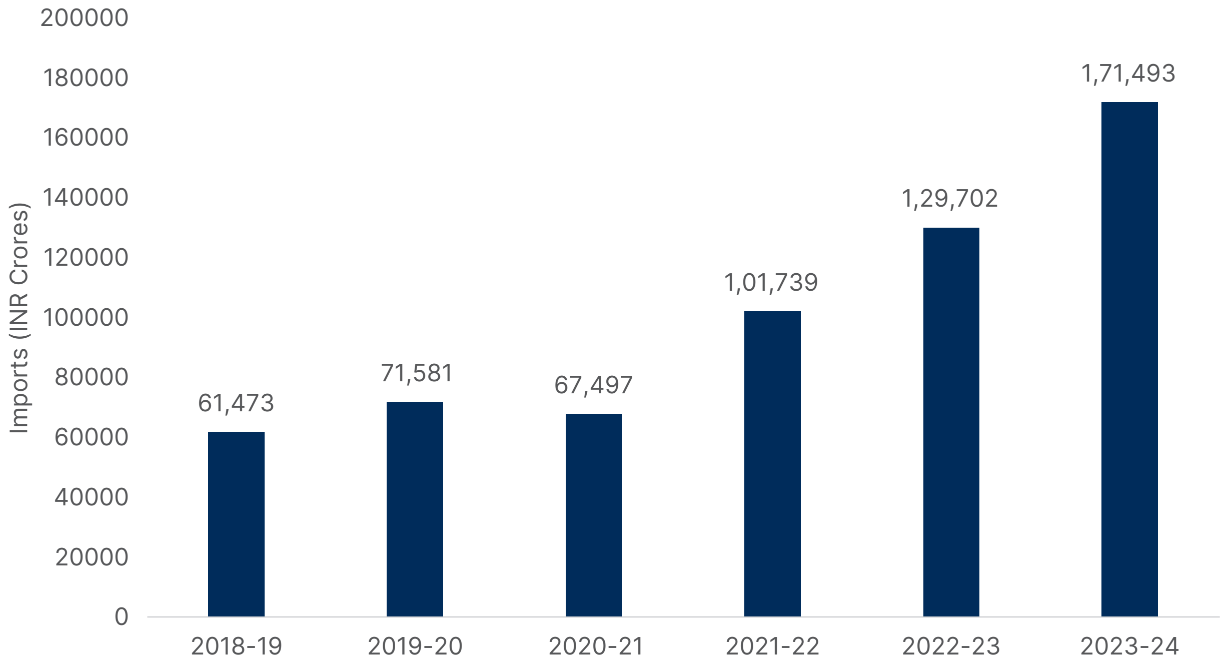
There are several Tier 1 component integrators, dependent on a relatively small set of

Figure 4.35: EV power electronics market size in 2030 (INR 000' Crores)



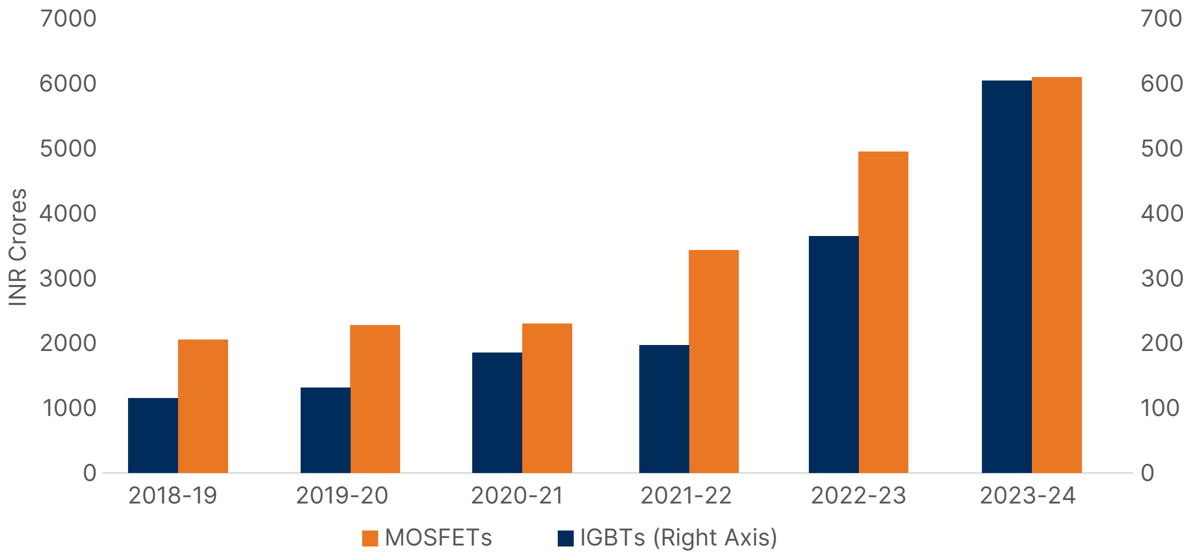
Source: RTI Analysis

Figure 4.36: India's imports of microcontrollers (INR Crores)



Source: Department of Commerce, Export Import data bank (HSN code: 8542)

Figure 4.37: India's imports of MoSFETS and IGBTs (INR Crores)



Source: Department of Commerce, Export Import data bank (HSN code 85412900 and 854121) semiconductor providers, who in turn depend on handful of wafer manufacturers. The lead time to shipment (time to ship the product upon order placement) varies significantly across different players in the semiconductor value chain. Supply chain disruptions severely impact automobile sector since the time and cost of securing an alternative is very high (Figure 4.38).

Localisation in EV Power electronics remains low as of now. However, it is expected to grow but not rapidly in the immediate future.

4.3 Automotive Software

The shift from traditional ICE vehicles using mechanical systems to EVs is reflected in increasing use of sophisticated software to manage batteries, motors, and powertrain. Though there are fewer moving parts in an EV, the amount of software used increases its complexity.

Automotive software encompasses all the applications and systems, which bring together data collection, processing, and user interaction. The objective is to enhance vehicles' functionality, safety, performance, convenience, and provide a more effective driving experience.

Vehicles managed and enabled primarily or entirely through software are called software-defined vehicles (SDVs). In its most basic form, software influences users' experience in many ways. Most vehicles, including recent ICE models, include some level of software and automation. More such features are expected to be added in the future. Customers' expectation of increasing reliability, convenience and entertainment is propelling the demand for SDVs.

More and more hardware components are digitally controlled now. This is leading to an increase in the number of software-based functionalities. SDVs have led to decoupling of network functions from the proprietary hardware components, enabling simultaneous physical and digital development and commercialisation of software (Deloitte, 2021). Software is thus disrupting the automotive industry by changing the way vehicles are designed, manufactured, and used.

Typically, the software developed for the automotive industry is common for similar applications in traditional ICE vehicles as well as EVs, with the later having a higher software content. Most software providers do not segregate their products by vehicle type i.e., EV or ICE. Same software can be used with minor changes to drive applications such as driver assist, infotainment, navigation etc. which are needed in both type of vehicles EVs have additional software for controlling drive train, thermal and battery management, which are not used in a typical ICE vehicle. However, given the small share of EVs, separate data for this segment is not readily available.

4.3.1 Technology Trends

The automotive market is increasingly being defined by user experience, digital customisation, and seamless ecosystem integration thus transforming the traditional emphasis from mechanical and electrical engineering (Deloitte, 2023). The hardware-led vehicle design process is moving to the one centred on software and services, thus making mobility encompass both the physical vehicle as well as a larger and more prominent software ecosystem.

Figure 4.38: Lead time to shipment for different players in the automotive value chain

Wafer production	Chip production/ Semiconductor device manufacturer	Tier 1 supplier	Vehicle OEM
Lead time to shipment	3-12 months	6-12 months	1-6 months
Time to secure an alternative	2-3 years	3-5 years	1-2 years

Source: X-Fab (2023); Primary interactions with companies

As already mentioned in Chapter 3, changes in the automotive industry are following the global technology trend of CASE (Connected, Autonomous, Shared, and Electric) vehicles. The growth of CASE is driven by advancements in automation and will result in changes in user behaviours and mobility preferences, shifting value pools (BCG, 2023), innovative business models (Oliver Wyman, 2018), and new entrants into the automotive sector.

The modules for which automotive software is developed includes, chassis, drivetrain, ICE/aux. systems, e-drive including battery, body structure, exterior, interior, and electrical/electronic architecture. Data processing, machine learning, and mapping make up the advanced software systems in automated vehicles. These advanced systems are categorised as the Internet of Things (IoT).

India's automotive software market by end-users can be segregated primarily into safety and security, infotainment, and instrument clusters, including vehicle connectivity. Increase in consumer demand for features like Advanced Driver Assistance Systems (ADAS) and automotive infotainment, reflects an expectation of reduction in risk of accidents, minimising fuel consumption, and enhancing the overall driving experience.

The application of software is especially noticeable in ADAS that allow use of applications like automatic emergency braking, pedestrian detection, surround view, parking assist, driver drowsiness detection, and gaze detection, among others. ADAS can enable various levels of autonomous driving (AD) as well as increase car and road safety.

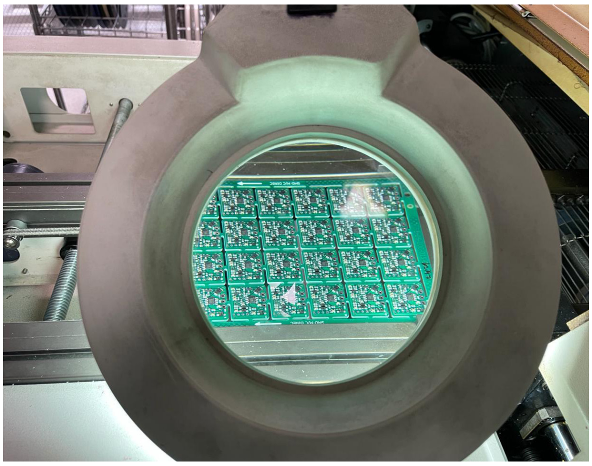
Automotive in-vehicle infotainment (IVI) systems present a unified interface, combining driving information including navigation, phone calls and vehicle settings with entertainment such as music. The ever-growing number of advanced features and wide array of technologies in IVI is redefining progress towards creating the automative cockpit of the future (Keil, 2018).

Autonomous driving, still in its early stages in India, is expected to evolve in the future. A five-part, formal classification level (L0 to L5), defined by SAE International, focuses on the degree of human intervention needed for driving (SAE, 2014; Revised 2021). Most current vehicles are partially automated i.e., in L1 and L2 category, but expected to evolve to fully automated (L4) and driver-less (L5) vehicles in the long run.

4.3.2. Market Size and Strategies

Globally, SDVs are expected to add USD 650 Billion to the automotive industry by 2030 contributing 15-20% of the total value (BCG, 2023). Though exact dollar-amount of value potential created differs among different sources, there is a broad consensus that the OEM revenues from automotive software and electronics are expected to increase three-fold (Capgemini, 2021), and the supplier market is expected to double by 2030 (BCG, 2023).

The automotive software market can be segmented by vehicle type (cars, LCV, and HCV), EV-specific applications (charging, battery management, and vehicle-to-grid or v2g), general applications (engine management & powertrain, connected services, autonomous driving, HMI applications, vehicle-to-everything or v2x system etc.), and by end-users (safety and security, infotainment etc.). Some key areas of increasing relevance of automotive software are listed in Figure 4.39.



Source: RTI

Figure 4.39: Automotive software development services

- **Motor Control:** Electric motor is at the heart of an EV. It needs an embedded software to control its functions, particularly the output. It is often controlled by a Field Oriented Control (FOC)-based system designed to yield maximum torque at the lowest speeds. The motor control software also includes modules that enable determination of speed, position, regenerative braking, among other related functionalities.
- **Transmission control:** Software adjusts the switching behaviour of the automatic transmission to the actual driving situation. The transmission control unit (TCU) performs a diagnosis of the automatic transmission and its components, making for a comfortable and dynamic driving performance.
- **Battery Management System:** EV batteries require an optimal set of operating conditions to function as designed. The Battery Management System (BMS) manages the battery pack and monitors various parameters to ensure safe and normal operation of the batteries.
- **Predictive Maintenance Software:** It enables identifications of problems and specific maintenance and repair needs. It guides the owner about maintenance needs and maintenance engineers to inspect specific components in accordance with the vehicle's requirements.
- **Safety systems:** Safety management systems power airbags, anti-lock brakes, and other safety features that reduce fatality risks thus helping protect drivers and passengers.
- **Driver assistance systems:** Adaptive cruise control, lane departure warning, and blind spot monitoring, are some features enabled by software that can make driving safer and more convenient. Some smart systems are capable of detecting other road users in complex situations, warning car drivers in time or even intervening autonomously in an emergency.
- **Telematics:** Software allows manufacturers and service providers, to communicate with vehicles, to provide remote diagnostics and over-the-air (OTA) updates.
- **Infotainment systems:** In-vehicle entertainment systems, navigation, and connectivity features are powered by software.

Source: Adapted from various sources including Bosch (n.d.); Perforce (n.d.) etc.

The vehicle development and use process is being altered by the increase in the amount of software being embedded. It is also evident that software needs periodic updates and fixes with most of these are made online and over-the-air (OTA). This shift is reflected in the expected growth of the global automotive OTA market from USD 3.3 Billion in 2022 to nearly USD 14 Billion by the end of the decade (Deloitte, 2023).

ADAS and AD software is expected to account for much of the growth, accounting for almost half of the software market by 2030, with infotainment, connectivity, security, and connected services growing apace with the market (McKinsey & Co., 2023). Propelled by the demand for ADAS, application of artificial intelligence (AI) in the global automotive market stood at USD 6 Billion in 2022 and is projected to expand at over 55% CAGR till 2032 (BCG, 2023).

Likewise, Electronic Control Unit (ECU) and Domain Control Unit (DCU) sales are expected to expand rapidly to USD 144 Billion by 2030, followed by software development (including integration, verification, and validation), with a revenue potential of USD 83 Billion (McKinsey & Co., 2023).

a) Third-Party Players

Currently, many OEMs rely on and work with third-party suppliers and technology vendors to provide services. According to a study by Ernst & Young, software in vehicles is linked to disparate hardware components which lead to distributed E/E architectures (EY, n.d.). Since the components are sourced from Tier-1 players, OEMs have little autonomy in implementing a centrally defined software strategy. Taking advantage of the expanding needs and changes in the OEM-supplier dynamics, the Tier-2s and pure-play software players are expanding into the market by engaging directly with the OEMs.

The software-driven automotive market is thus altered by third parties providing services and software. Some OEMs have begun to work with specific software and technology service providers in building strategic partnerships (establishing centres of excellence and dedicated laboratories), to improve the agility and scalability of software development. Third-party supplier market for automotive software and electronics is expected to double by 2030 (BCG, 2023).

b) OEMs

OEMs are taking a multi-pronged approach to adapt to the change brought by the increasing use of software. They are investing in software capabilities and prioritising partnerships with or acquisition of third-party players.

Some OEMs are undertaking strategic, and in some cases exclusive, partnerships with Tier 2 as well as pure-software companies, to overcome their immediate technology constraints.

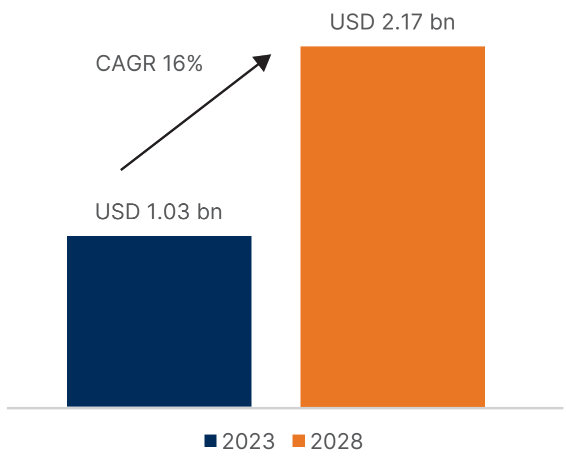
However, almost all OEMs in the long-term expect to gradually build in-house expertise and competence, and co-develop their own platforms and software, thus allowing better control over development, deployment, and implementation. This is expected to improve their productivity and efficiency while also allowing them to differentiate themselves for their software offerings.

Software-based features and services are expected to be a key source of revenue for the OEMs, in global terms growing from about 8% of their current annual revenue to 22% (Capgemini, 2021). The impetus for software-driven transformation for OEMs is reflected in some frontrunners establishing a significant lead with twice the average revenue of their peers, and by 2031, expecting software to account for 28% of their revenue (Capgemini, 2021).

4.3.3 Indian Landscape

SDVs and electric mobility are set to drive India's automotive software industry. The country's automotive software market, Figure 4.40, is

Figure 4.40: Indian automotive software market forecast



Source: Research & Markets (2023)

estimated at USD 1.0 Billion in 2023, and is expected to reach USD 2.2 Billion by 2028, growing at a CAGR of 16% (Research & Markets, 2023). India being home to almost 75,000 pure software employees in the automotive sector makes it the second largest geographical player, after the USA in this domain (HashList, 2023).

The Indian automotive industry's growth is attributed to two segments: a) Changing consumer preferences and infrastructure development as reflected in the growing acceptance of SDVs. This is propelling automotive software growth; and b) the demonstrated interest of global automakers in Indian companies and workers to develop software for driverless cars and other innovative technologies (Economic Times, 2023).

Indian customers' interest in vehicles with advanced features is reflected in almost 80% of respondents to a survey embracing the benefits of increased connectivity, compared to 46% in the United States and only 36% in Germany (Deloitte, 2020).

The Indian automotive industry's embrace of advanced technologies, digitalisation, and collaboration with technology companies positions it at the forefront of innovation in the global automotive landscape. This convergence helps companies leverage their deep domain expertise across product engineering, software, electronics, connectivity, mechanical engineering, industrial networking protocols, industrial internet of things (IIoT), smart industry products, test frameworks, and enterprise control systems to support global customers.

In emerging trends, Indian companies are developing near-shore state-of-the-art design centres. For example, aside from India, L&T Technology Services has multiple design labs in Europe, the United States, as well as the Middle East, to cater to new age digital requirements of the global automotive ecosystem, railways, ER&D, aerospace, and defence sectors (L&T TS, 2023). Also in 2022, investing GBP 100 Million over the next five years, Ola Electric announced the setting up of FutureFoundry, its global centre for advanced engineering and vehicle design, in Coventry, UK. It will work in-synch with the design and engineering teams of Ola in India. It will house global talent across multiple disciplines of 2W and 4W vehicle design, advanced high-performance automotive engineering, digital & physical modelling among others (OLA, 2022).

Indian companies are not only leading but are also being recognised for their design and technology services. To give just one example, Tata Elxsi has been at the forefront of design excellence. It won the international iF Design Award 2017 for design excellence (Tata Elxsi, 2017), the e4M India Design Excellence Award for HMI design in NEXON EV in 2023 (Tata Elxsi, 2023), and the Gen 3 HMI cockpit design for electric and ICE vehicles, and also winning an international design award (German Design Award, 2024).

a) *Players in the Automotive Software Space*

Several top OEMs in India, like Tata Motors, Mahindra & Mahindra, MG Motor India, Hyundai Motor India, Maruti Suzuki India, Renault India, Nissan India, Ather Energy, Hero Electric, and Okinawa Autotech are leveraging their networks and collaborations for growth in the product and software development segments. Many of the leading Indian software companies have a presence in the automotive software domain and an indicative list is included in Figure 4.41.

Start-ups in the automotive domain range from new players in electric vehicles manufacturing to brands that provide software solutions to local and global players. Some notable startups in this domain include Ola Electric, Flux Auto, Intangles etc. The increasing indigenisation of automobile manufacturing and software sectors is expected to provide a boost for India to emerge as a global leader.

b) *Investment in Automotive Software*

India's emergence as the new automotive technology hub because of a strong domestic ecosystem of innovation and manpower is

Figure 4.41: An indicative list of leading indian automotive software companies

Company/Groups	Features/Offerings
Tata Technologies	Computer-aided design (CAD) and computer-aided engineering (CAE) tools, product data management (PDM) and product lifecycle management (PLM) systems, simulation and analysis.
KPIT Technologies	Has global presence with offices in North America, Europe, and Asia-Pacific.
Infosys	Product engineering services include software development, testing, and validation for automotive systems such as infotainment, telematics, and safety.
Wipro Ltd	Product engineering, digital transformation, and consulting.
HCL Technologies	Product engineering services include software development, testing, validation, and integration for automotive systems such as infotainment, telematics, and advanced driver assistance systems (ADAS). Also provides digital solutions such as IoT, cloud computing, and analytics.
Tech Mahindra	Product engineering, digital transformation, and consulting. The company's product engineering services include software development, testing, and validation for automotive systems such as infotainment, telematics, and ADAS.
QuEST Global	Product engineering, digital transformation, and consulting. Offices in North America, Europe, Asia-Pacific, and the Middle East.
L&T Technology Services	Product engineering services include software development, testing, and validation for automotive systems such as infotainment, telematics, and ADAS. Also, has consulting division.
Tata Consultancy Services	Product engineering services include software development, testing, and validation for automotive systems such as infotainment, telematics, and ADAS. TCS also provides digital solutions such as IoT, cloud computing, and analytics.
Cyient	Product engineering, digital transformation, and consulting. Product engineering services include software development, testing, and validation for automotive systems such as infotainment, telematics, and ADAS.
Others include Bosch India, Accenture, Aricent, Altair Engineering, Persistent Systems and Geometric with various offerings.	

Source: Adapted from Inventiva Report (2023) evident from the fact that global companies like the US-equity-firm KKR-backed Marelli to the Swedish Volvo Group, Magna International to BorgWarner, and more recently BMW and FTP, all are investing in the country. A list of recent investments in automotive software is included in Figure 4.42.

In recent years, there has been significant interest and growth in establishing global capability centres (GCC) for automotive and manufacturing sectors (Economic Times, 2023). Many domestic and international players are establishing state-of-the-art facilities in hubs like Bangalore, Pune, and Chennai attracting These centres provide engineering and services design, cost engineering and testing services, thus providing a boost to the automotive software industry in the country (NITI Aayog, 2020).

Figure 4.42: Select investments in automotive software

S.No.	Company	Features	India HQ	Geographies
1	Allygrow Technologies Pvt. Ltd.	Virtual validation, electrification, plant automation/IOT	Pune	North America, Europe, UK
2	Alpine of Asia Pacific India Pvt Ltd	Audio Visual and Navigation System	Gurgaon	Japan, Asia & Oceania, Europe, North America
3	BlackBerry India Pvt Ltd.	QNX Sound, QNX ADAS Platform, Blackberry IVY	New Delhi	Canada, North America, Europe, China, Korea, India
4	Elektrobit India Pvt. Ltd	Embedded and connected software, automotive cyber security	Bengaluru	Germany and branches in Asia, Europe, and North America
5	Hella India Pvt. Ltd.	Body control modules, Car Access Passive Entry, Remote Keyless Entry, Smart Mood Lighting, Reverse Park Assist System, Immobilizer, Connectivity Solutions	Gurgaon	Forvia Hella has presence in in around 35 countries
6	GlobalLogic (Hitachi Group company)	Digital cockpit: Integrated cockpit, infotainment, instrument clusters, HUDs, Android Auto /CarPlay integration	Noida	Across major geographies
7	BMW Group & TATA Technologies	Automotive software, software-defined vehicle (SDV) solutions and business IT solutions	Bangalore, Pune, Chennai	Germany, Mexico, USA, South America, South Africa, UK, India, China

Source: RTI Research based on annual reports, company websites and press articles

In the last three years, the automotive software sector has seen keen interest from foreign investors. For example, Stellantis is establishing two software hubs in Bengaluru as its main technology development centre. The OEM aims to generate an additional EUR 20 Billion in annual revenues by 2030 from this investment in software-driven strategy (Stellantis, 2022).

A different example is Ford, which stopped manufacturing vehicles in India but continues to invest in technology, software, and related services. It has invested USD 250 Million in the past five years to expand its Chennai technology hub, i.e., the Ford Business Solutions. It announced further investments in building EV software capabilities for its global platforms at its Chennai hub (Economic Times, 2024).

Indian software companies and OEMs, with their trained manpower and the potential to deliver digital solutions, are also undertaking strategic-tie-ups to leverage the disruptions caused in the automotive sector. For example, in April 2024, the BMW-Tata Technologies joint-venture partnership was announced which will provide automotive software solutions for BMW's premium vehicles and digital transformation solutions for its business IT (BMW Group, 2024).

In March 2024, Wipro teamed up with General Motors and auto-parts supplier Magna to form a joint venture, SDVerse, that aims to link buyers and sellers through a digital platform (Wipro, 2024). In January 2024, FTP announced its automotive technology subsidiary and opened its office in Pune, India (FTP, 2024).

Another partnership announced in January 2024, for product development, engineering, manufacturing, and digital services to further advanced (urban) air mobility, was between Cyient and SkyDrive, a Japanese eVTOL aircraft manufacturer (Cyient, 2024).

In 2023, the Renault Group chose KPIT as a strategic technology partner for co-developing their next generation SDV program (KPIT, 2022). KPIT had previously acquired Munich-headquartered Technica Engineering (in 2022), thus creating an across-the-stack expertise offering a one-stop shop for the industry to transition towards SDVs (KPIT, 2022).

In 2022, Blackberry expanded its global auto software business in India by collaborating with Mahindra & Mahindra (Blackberry, 2022). Marelli inaugurated its new Technical R&D Centre in Bengaluru in 2022, thereby bolstering the company's innovation capabilities, particularly in software engineering (Marelli, 2022). The US-based Tier-1 company, Magna International, invested USD 120 Million to establish a new engineering-centre supporting e-mobility in Bengaluru (Magna, 2022).

The Volvo Group in 2022 set up a new 'Vehicle TechLab' India, the first outside of Sweden, with cutting-edge technologies like a virtual reality (VR) zone, human body motion tracking & realistic digital rendering of vehicles, a driving simulator, mock-up chassis space and an electromobility zone for development of power electronics for EVs, thus allowing global connect & collaboration (Volvo, 2022).

Indian players are also increasing both their technology-muscle and bench strength by forming international collaborations and taking the acquisition route. In 2023, HCL acquired the German automotive engineering and software services firm ASAP Gruppe, leveraging it to further expand into markets in Europe, Americas, and Japan (HCL, 2023). Tech Mahindra has partnered with Anyverse in August 2023, to accelerate AI adoption in the automotive industry (Tech Mahindra, 2023). The partnership simplifies the use of synthetic data to train, test, and validate AI systems for global customers in the automotive industry. Cross-company collaborations and partnerships among technology companies, OEMs, and start-ups, is expected to foster innovation, accelerate the growth of new technologies, and drive industry transformation. While the technology companies bring expertise in software development, AI, IoT, and data analytics, the automotive manufacturers contribute their domain knowledge and manufacturing capabilities.

4.4 Challenges

While the advancements discussed above suggest a strong and entrepreneurial ecosystem for automotive software in India, some challenges remain. These include the high investments required in people, technology, and infrastructure. Further, rising customer expectations and rapidly evolving technology create time pressures of shorter innovation cycles; challenges of multi-industry technology integration; and the need to adhere to complex standards across markets and industries.

Given the trends, there is a need to develop adaptability and agility to keep up with innovations and advancements, thus ensuring competitiveness. Additionally, time-consuming, resource-intensive, and rigorous testing required for and dealing with cybersecurity adds a layer of complexity. Another dimension to these challenges relates to compliance to regulatory, security, and emission standards and adhering to safety standards.

India boasts the second largest automotive software workforce. Inputs provided to RTI during consultations also reflect the recognition in the industry for further developing automotive software talent. Leading organisations, OEMs, as well as Indian pure-play software and engineering companies, are investing in developing manpower, both in-house and in collaboration with academia.

The need for automotive software and technology companies to navigate complex global-local automotive standards with differentiated geo-specific requirements is an evolving challenge. Aside from the adherence to technical standards, risks arising from legislations like the EU and UK General Data Protection Regulations (GDPR) that have extraterrestrial scope, as well as the DPDPA needs to be factored. The Indian automotive software companies thus need to build systems and processes providing for such data protection and compliance.

Aside from targeted investments and furtherance of cross-industry collaboration, in our consultations, it has been pointed out that the Indian auto software industry will benefit from sound cybersecurity regulations, especially as vehicles become more connected, thus becoming vulnerable to hacking and data breaches (6W Research, 2023). The introduction of 5G services in 2022 provided an impetus to the connected automotive industry, enabling internet access allowing for the transformational work-from-car and bank-in-care trends (HCL, 2024). Given the vehicles are now akin to computers and data centres on wheels, the public as well as the industry favour strong cyber protections (Thales, 2023). In that direction, the UNECE WP.29 (UNECE, n.d.) is a working party aiming to provide a platform for international collaboration on automotive regulations, ensuring safety, environmental protection, and trade efficiency. The WP.29 CMS (Cybersecurity Management System) regulation requires robust cyber security throughout the vehicles' entire lifecycle from design to decommissioning, however, wide-spread adoption of the framework has been a challenge.

Automotive and mobility players, incumbents as well as new market entrants, have an opportunity to rethink vehicle design, build, sales, operation, and maintenance (BCG, 2023). With targeted investment in vehicle platforms and new technologies, India can achieve global scale in software and engineering-research-and-development (ER&D). Enabled by manufacturing, innovation, and technology leadership, the country can build an export-led industry of USD 1 trillion by 2035 (Arthur D. Little, 2023).

4.5 Summary

There is a significant import dependence in case of EV powertrain and power electronics components. This is due to lack of domestic manufacturing competency in niche areas such as magnet production, electrical steel laminations, semiconductors, availability of technical expertise and specialised equipment amongst other challenges. It is expected that localisation of motors and controllers will increase significantly during the next five years. However, in the case of power electronics, the progress may require more time. While some investments have been announced and are under active consideration, their maturity and specific outcomes are currently uncertain. Therefore, at this juncture it appears that power electronics may still have a relatively high import dependence by 2030.

Continued efforts to improve enabling environment, supportive policies, new programmes, innovative pilots, joint ventures, and international collaborations will remain relevant. These are discussed in more detail in Chapter 5.

Source: RTI

5. ACTION PLAN

Make your plans as fantastic as you like, because 25 years from now, they will seem mediocre. Make your plans ten times as great as you first planned, and 25 years from now you will wonder why you did not make them 50 times as great.

Henry Curtis

Source: MS stock

5.1 Strategies and Roadmap

This chapter discusses strategies to enhance and accelerate domestic manufacturing of electric vehicle components. The imperative for localisation is driven by the strategic importance of the automobile sector for India's economy. Localisation is also critical for India's energy security as a large proportion of crude oil continues to be imported. Accelerated e-mobility transition will also enable faster progress on India's ambitious climate goals and towards improved air quality in cities. These objectives are key to accelerated development, growth and for generating livelihoods, over the coming decades.

From the industry perspective it is critical to address various barriers, both on the demand and the supply side, particularly for enhancing localisation. Addressing demand side is equally critical given that the transition is in a nascent stage and large investments are required over the coming years. Therefore, the roadmap presented herein suggests various strategies that can be adopted by stakeholders to ensure dynamic growth in both demand and supply of electric vehicles. Further, actions are proposed for the short to medium term as well as those relevant for the longer term. Steps taken in short term will have a bearing in the future and hence follow on actions will need to be calibrated based on progress made and lessons learnt from actions taken in the short term. It will also be relevant to keep a close watch on technological advancement and market developments on an ongoing basis to ensure that actions are aligned to the stakeholder needs. Therefore, a calibrated approach based on regular monitoring and feedback is suggested.

To enable accelerated progress, academic institutions, R&D bodies, testing centres, financial institutions etc. will need to be part of the process in addition to the Government and the industry. A collaborative and consultative process involving various stakeholder is use therefore recommended. An Industry Working Group is use hence proposed to be constituted and hosted by one of the leading industry chambers.

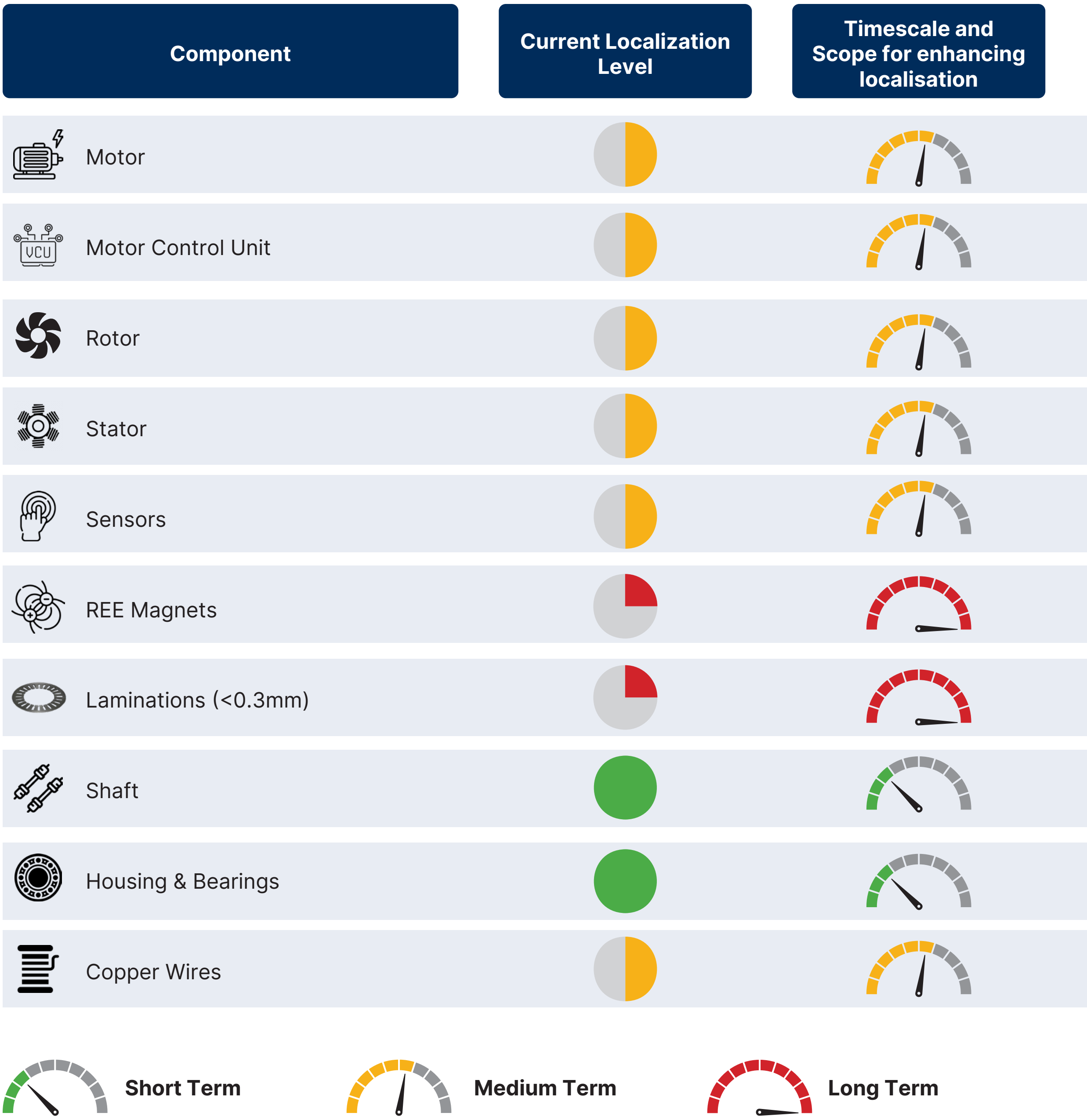
5.2 Supply Side Analysis and Barriers

E-mobility transition requires a strategic emphasis on domestic manufacturing as the shift is not only a technological evolution, but a large economic opportunity. Crucially, around 65-75% of the Bill of Materials (BOM) of an EV comprises of new components, signalling a transformative moment for the industry. The traditional ICE components will be replaced by newer components such as electric motors, batteries, and power electronics, requiring a different set of manufacturing capabilities. Since this is a global shift, most countries currently lag in production of these components. A review of current localisation levels as presented below enables forward looking plans and strategies as outlined in this chapter.

5.2.1 Powertrain

This analysis highlighted a significant import dependence of power train, especially components such as permanent magnets that constitute a significant part of the BOM, particularly for PMSM motors that are commonly used in EVs. As mentioned, the current localisation level for powertrain is about 50% for 2W and 3W, but less than 20% for other segments. It is expected that the localisation for 2W and 3W categories will increase over the next few years. However, additional efforts are required in other categories, especially heavier vehicles. This is because of uncertain demand, high investment needed and technological challenges such as advanced motor design and lack of capabilities. Figure 5.1 provides an overview of the current localisation level and the potential for enhancement over the coming years.

Figure 5.1: Localisation prospects for powertrain

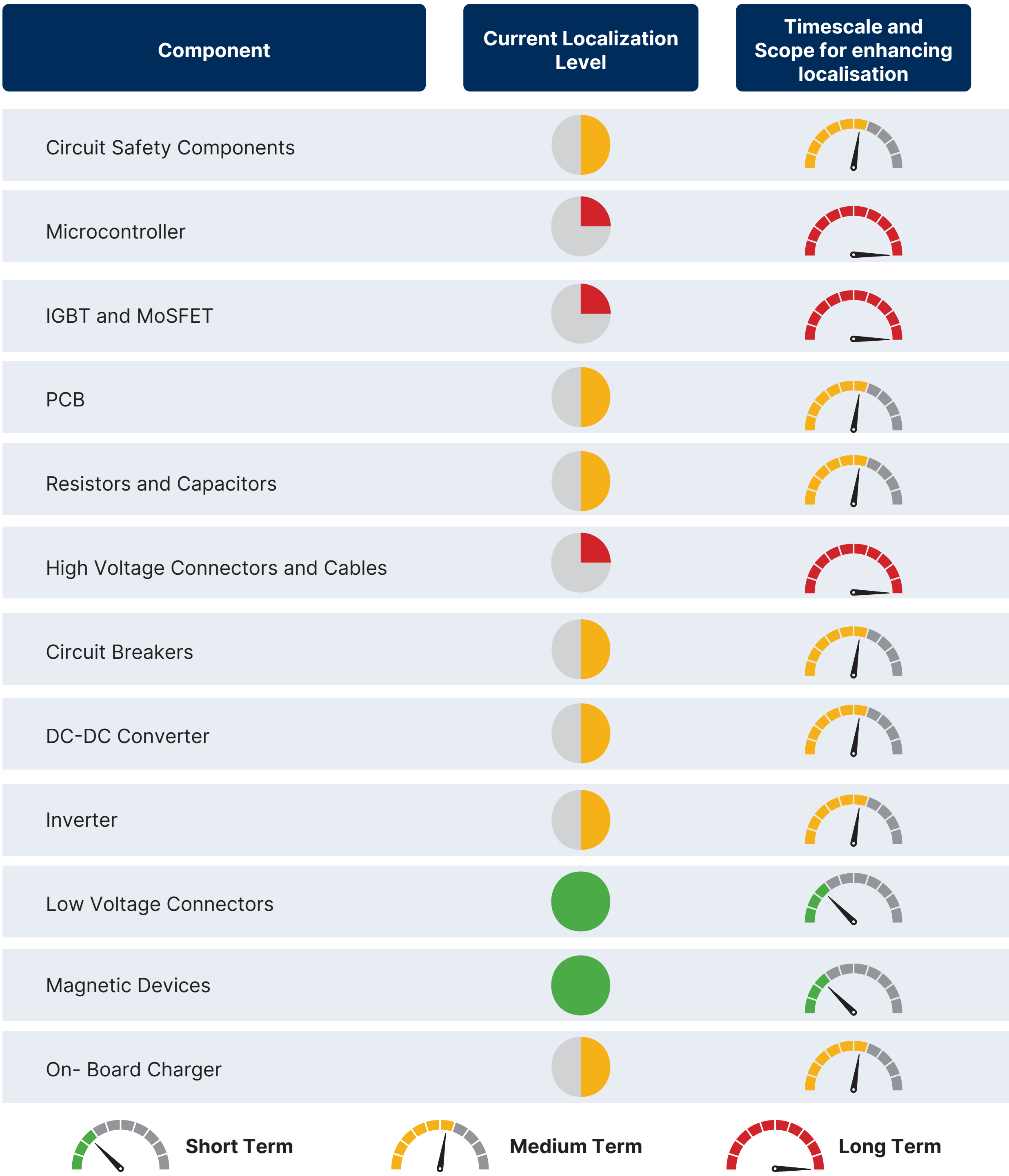


Source: RTI Analysis

5.2.2 Power Electronics

Localising power electronics will depend mainly on semiconductor production. Domestic capabilities in the semiconductor value chain are currently low and will take a few years to start production. Local manufacturing of rectifiers and controllers is also dependent on semiconductors, but with local components not readily available, makes imported assembled modules significantly cheaper. Therefore, power electronic components will have to depend on the imported content in the interim. Further, downstream processing capabilities for REEs are lacking (DST, 2024). In terms of connectors and charger assembly, availability of low-cost imports is a constraint to domestic manufacturing (NITI Aayog & BCG, 2022). Figure 5.2 provides an overview of the

Figure 5.2: Localisation prospects for power electronics



Source: RTI Analysis

current localisation level and the potential for enhancement over the coming years.

Overall, localization levels in powertrain and power electronics are currently modest. Significant efforts will therefore be needed by all stakeholders to achieve increase localization and integrate India in the global value chains. The PLI scheme is a major initiative from the Government and some progress is likely through the same. The industry, particularly OEMs will need to play a more active role to enable and support development of the domestic ecosystem for component and sub-component manufacturing in the short to medium term.

Given the current modest level, it is evident that there is a significant potential for increasing localisation of sub-components such as copper windings, steel lamination, controllers, software, and telematics, presenting opportunities for increasing output for local and international markets, especially for heavy vehicles such as buses and trucks. Some of these components are already incentivized under PLI schemes, but others are not. It is likely that PLI schemes will enable domestic manufacturing capabilities in the assembly of Printed Circuit Boards (PCBs), thermal management systems, circuit safety, and battery packs in the coming years. However, enhancing localisation of components like PMSM motors, DC-DC converters, controllers, and GPS modules may require a longer timeframe.

5.3 Constraints in Expanding Domestic Manufacturing

This analysis revealed that while localisation is supported by all stakeholders, several barriers still exist. These constraints to expanding domestic manufacturing can be categorised broadly in two categories.

1. Industry Specific: At the industry level, factors like technology, financing, skilled labour, supply chain efficiency, and regulatory frameworks etc. that have a direct bearing on the localisation outcomes.
2. Ecosystem Barriers: Systemic challenges relating to infrastructure constraints and costs, trade and taxation policies, and global economic trends also influence the overall manufacturing environment

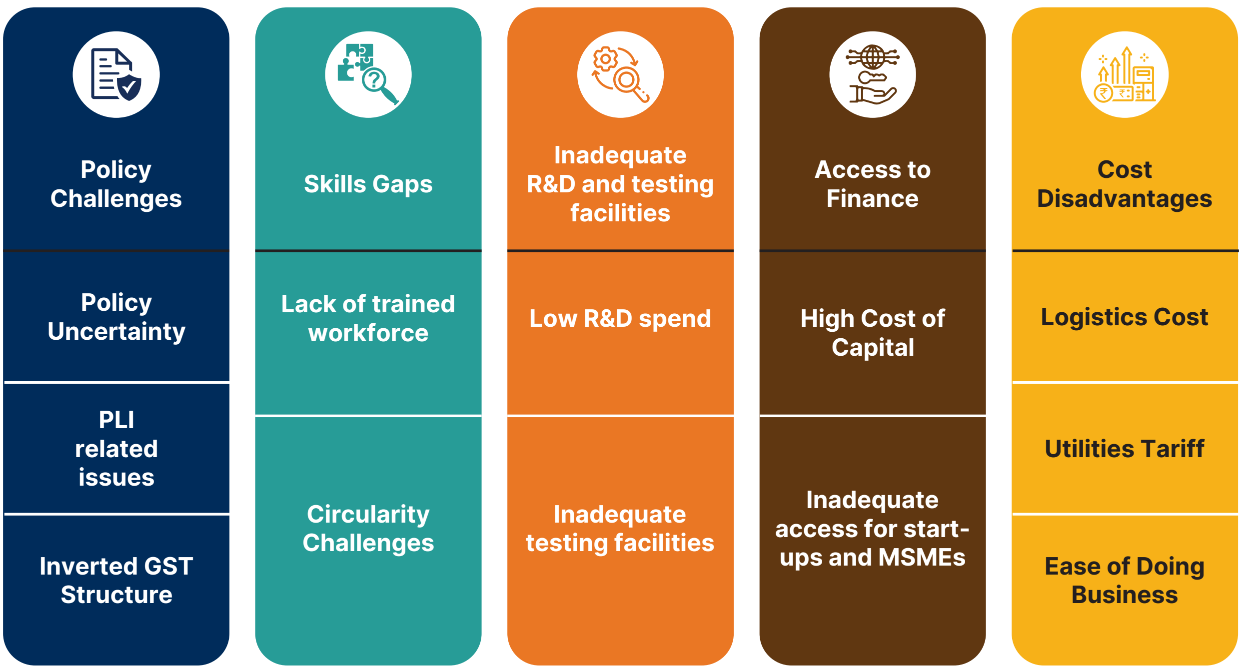
Figure 5.3 summarises the key constraints at the industry as well as ecosystem level and the following sub-sections briefly outline the main challenges within each sub-category.

The supply side challenges are discussed in this section. Beyond these, uncertainty of demand in the long term is a key barrier that needs to be addressed to enable large investments needed to enhance localisation. Issues relating to the demand side are discussed in the next section i.e., 5.4.

5.3.1 Policy Issues

Industry stakeholders provided feedback on three major policy issues. The first relates to

Figure 5.3: Key constraints to expanding domestic manufacturing



Source: RTI Analysis

need for policy certainty, the second regarding the auto PLI scheme and the third about the inverted GST structure.

E-mobility transition requires large investments in a new and emerging technology. Several stakeholders commented that adoption and availability of EVs are equally challenging i.e., there are uncertainties regarding both demand and supply side of the market. Further, the need for large investments, skills and time required was again universally highlighted. It was in this context that a comprehensive and detailed policy, outlining the vision for the sector came up in several discussions.

Production Linked Incentive (PLI) schemes have been launched by the Government of India across 14 key sectors to enhance India's domestic manufacturing capabilities and exports. The purpose of these schemes is to attract investments, introduce cutting-edge technology; ensure efficiency and enhance economies of size and scale to make Indian companies and manufacturers globally competitive.

Several of these schemes such as Automobiles and Auto Components, Advanced Chemistry Cell (ACC) Batteries, Electronic components etc. have a bearing on manufacturing of EVs in the country.

These schemes were considered to be a step in the right direction by stakeholders. However, some challenges were noted by several industry stakeholders, particularly in relation to the automobile and auto components scheme discussed below.

Industry stakeholders conveyed that some of the criteria under the scheme were challenging to fulfil. They highlighted the difficulty in achieving all mandatory conditions to avail incentives. For instance, while some approved components may meet 50% DVA criteria, being low volume and low margin products, it may not be possible for those to meet cumulative new domestic investment of INR 250 Crores by March 2028 as required. Further, for low volume, low margin products (e.g., DC-DC converters), it may not be possible to meet the year-on-year incremental sales criteria. Some leading players highlighted differences with the PLI scheme for mobile manufacturing, which has achieved considerable success. They pointed out that the DVA increased from almost 0% to about 20% for mobile phones (PIB, 2023).

Industry players also pointed to relatively complex process under the auto and auto components PLI scheme compared to other schemes. One such requirement pointed was the need for external assessment and audit. Therefore, the auto components scheme appears administratively complex and burdensome. Standardisation and cross-learning from successes achieved under one or the other PLI schemes in measuring and monitoring DVA norms was mentioned as an avenue to pursue.

Another option highlighted in the industry consultation was to consider aggregate domestic value addition versus domestic value addition ratio (DVAR) in a particular organisation or industry. This argument has also been made by the Indian Cellular and Electronics Association (ICEA) in their vision document for electronics manufacturing (ICEA, 2022). Their analysis asserts that China and Vietnam have gained ground in manufacturing owing to a focus on aggregate domestic value addition, instead of DVAR. Their study cites that despite building up a manufacturing ecosystem for decades, China's DVA in electronics manufacturing stands at 25-40%, depending on the product category. Their recommendation is to focus on scale and output, rather than DVAR alone.

It is evident that EV specific components are yet to achieve scale in India. Under the FAME II, phased manufacturing programs (PMPs) were designed for EV parts and EV charger parts. As per the PMP, OEMs had to achieve localisation for several parts by the stipulated deadlines. However, the deadlines had to be moved forward several times. A similar case emerges in the PMP for EV charger parts. In November 2023, the Ministry of Heavy Industries amended the deadlines for localisation in EV charger parts as well. This suggests that the domestic supply base for EV components is still in a nascent stage. OEMs have been driving tier 1 localisation through some local value addition, however, localisation at the tier 2 level and below is lacking (PwC, 2022).

During consultations, many stakeholders also pointed to a need for introducing incentives for design of components in addition to their actual production. Further, investments for technology transfer and in R&D are not eligible under PLI and many recommended these to be additionally considered. Some incentives are however available for select electronic components under different scheme, i.e., the Design Linked Incentive scheme as a part of the India Semiconductor Mission launched by the Ministry of Electronics and Information Technology.

Another pathway highlighted by stakeholders relates to creating sub-categories with a focus on components that are relatively easier to localise. For example, motors have been manufactured in India for a long time. Sub-assemblies such as windings are also manufactured and can be scaled relatively quickly. Likewise, controllers and hall effect sensors can be localised faster than some of the other sub-components such as magnets. From the perspective of localisation, it may be useful to consider sub-categories within existing PLI.

PLI scheme for auto components was argued to exclusively target large players and focussed on high value manufacturing. However, MSMEs which comprise a large part of the automotive industry (Tier 2, Tier 3) and start-ups in the EV sector. These players are unable to take advantage of incentives offered under this scheme even though they plan an important role in the value chain.

The other major policy related issue highlighted during consultation was the inverted GST structure for EVs. For EVs, GST was reduced to 5% in 2019 and has provided a demand impetus. However, GST on spare parts and components continues to be in the 18%-28% range, creating an inverted gst structure (SMEV, 2023). This locks up working capital of manufacturers, thereby increasing their costs. This results in higher prices of domestic components relative to imports thereby is contrary to the localisation imperative. Further, sometimes it also ties up management bandwidth in unnecessary regulatory and legal cases. Therefore, it is important to reconsider the GST structure. The case for reduction in GST on batteries was considered by the GST Council in October 2023. However, it was decided that those will stay in the 18% slab since Li-ion batteries have applications beyond EVs (Economic Times, 2023).

While the overall policy environment is supportive of localisation, some tweaks within the existing PLI schemes and rationalisation of GST structure will enhance effectiveness of the incentives and offer a stronger signal for investments.

5.3.2 Skill Gaps

There is inadequate availability of a skilled workforce in mechatronics, simulation, and related embedded software development. Mechatronics is a core skill set required for EV powertrain development. It integrates mechanical and electronics, actuators, and sensors, all controlled by software. Industry stakeholders stated a lack of industry trained talent in simulation tools and platforms (ANSYS, Simulia OPERA, Altair Flux motor etc).

It was also noted by the stakeholders that recruiting and retaining skilled staff with skills in power semiconductors, converters, and inverter systems is a challenge. While talent is available for semi-conductor design, but semi-conductor manufacturing related skills are not readily available.

India will require 10,000-13,000 trained engineers and technicians by 2027 for chip manufacturing industry (The Hindu, 2023). However, there is a lack of sufficient candidates with required qualifications such as M. Tech. or PhD. in semi-conductor fields to bridge this gap (Ezell, 2024). There is a need for a dedicated Power Electronic Machines and Drives Skills Centre, which can connect be a platform for training and education providers and willing professionals and students.

Another gap is the limited know-how among component manufacturers on product level circularity or closed loop processes. Further, design capabilities to develop components and products optimised for future use (reuse or recycle etc.) is limited. Specifically, knowledge gaps exist in areas such as improved design and manufacturing considering circularity as well as scientific dismantling of end-of-life components to enable recycling and reuse of high value sub-components such as magnets.

5.3.3 Inadequate R&D and Testing Facilities

While many startups are focussing on R&D and are committed to investing in technology trials, testing and validation, the overall R&D remains below the desired level. Average R&D expenditure as a share of revenue is approximately 2% (Figure 5.4), much less than 7-8% spent by top global automotive companies. A key measure of outcomes is the intensity in using foreign technology and its growth.

According to recent research (Basant, 2021), it is noted that the use of disembodied as well as embodied form of foreign technology in transportation and electronics sector, is significantly higher than the average for all manufacturing. Further, the growth rate over the last three decades has been higher in these sectors relative to the average of all manufacturing combined. This clearly indicates inadequate investment in the country and is an area of concern because R&D is critical for enhancing localisation of manufacturing.

Further, product development is often reported by companies under the R&D head. A few manufacturers such as Uno Minda, Bosch, Sona Comstar and Varroc have a higher-than-average R&D spend. These manufacturers also have a high revenue share from EV business and an expanded range of EV components in their portfolio.

Figure 5.4: R&D spend by top auto component manufacturers (based on turnover)

Company	Turnover (Crores)	EV share in Revenue	R&D (% of revenue)
Motherson Sumi	78,701	6%	0.39%*
Bosch Limited (India)	14,929	-	3.00%
Bharat Forge	12,910	-	0.77%
Uno Minda	11,236	11-12%	4.00%
Cummins India Limited	7,612	-	0.35%
Endurance Technologies	8,849	4%	0.92%
Mahindra CIE automotive	8,811	35%	-
Varroc	6,863	5%	2.20%
Spark Minda	4300		3%
Sundaram Fasteners	5,708	3%	0.16%
Sona Comstar	2,675	26%	2.70%
Napino	1228		3%
Lucas TVS			3%
Anand Mando			2%
Average R&D spend			2%

Source: RTI Analysis, Company annual reports. ** FY21 data*

"Setup Center of Excellence for each component at CoEs set up by academic institutions, backed by industrial forums to maximize output."

A Leading EV manufacturer during a stakeholder consultation workshop conducted by RTI

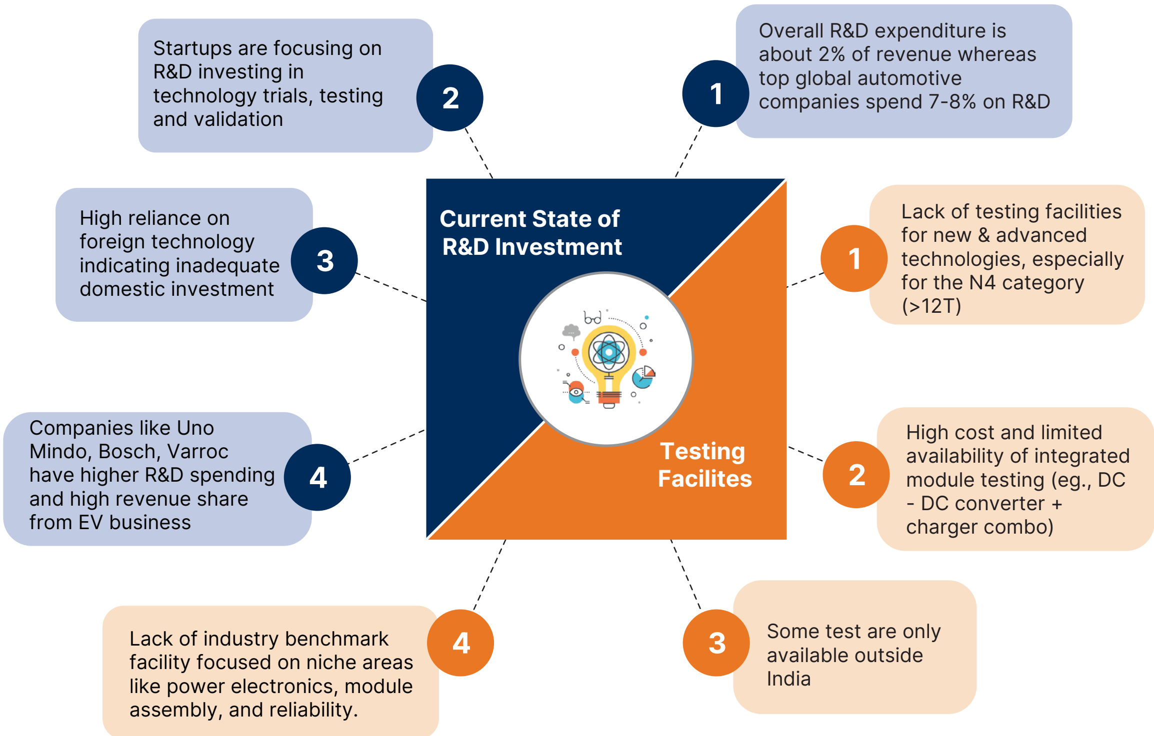
A related challenge faced by the industry is inadequate testing facilities, especially for new and advanced technologies.

Four testing centres (Automotive Research Association of India (ARAI), International Centre for Automotive Technology (ICAT), National Automotive Testing and R&D Infrastructure Project (NATRiP) and Global Automotive Research Centre (GARC)) focussed on different areas of EV testing are operational. For the N3 category (>12T), many tests are not available in India. Such tests are performed in facilities outside India that ARAI and ICAT has access to. Further, motor technology testbeds or shared facilities are few and far for new, evolving motors for design and pilot testing. Such facilities are however critical for start-ups and smaller companies with limited capital and resources. Common facilities are therefore necessary for research, product development and prototyping.

Another challenge relates to testing components such as converters in real life drive cycles. For simulation environment (hardware-in-the-loop/ software-in-the-loop simulator) which facilitate various scenarios (loading), traffic context is required, but not readily available. Further, testing of integrated modules (e.g., DC- DC converter + charger combo) at the vehicle level was considered expensive.

Several manufacturers cited the need for an 'industry benchmark facility' focussed on niche areas such as power electronics, module assembly, reliability, and robustness. Figure 5.5 summarises the challenges related to R&D and Testing in India.

Figure 5.5: Current state of R&D investments and EV component testing in India



Source: RTI Compilation based on Industry Consultations

Tamil Nadu has plans for setting up a common facility centre in Coimbatore for EV motor development and testing under the Micro-cluster development programme. Such centres in auto clusters will accelerate the development of EVs and were considered desirable in different parts of the country. It was suggested that these should be open access for all and in addition to testing, will foster collaboration between industry and academia.

Some leading component suppliers have established their own testing facilities incurring large investments. It is also possible that they may make them available to other manufacturers for testing.

While these are large investments, they will diminish with development of technical expertise and a learning curve. It is therefore relevant that they are developed as public facilities or as joint facilities to reduce the burden on individual industry players, especially start-ups and smaller companies.

5.3.4 Access to Finance

Manufacturing EV components is a capital-intensive business that requires significant upfront investment. An analysis by Singh, Chawla, and Jain (2020) noted that larger OEMs in India can access finance. Similarly, Tier-1 manufacturers connected to the larger OEMs may be able to access capital markets. However, financing is an acute challenge for smaller companies, particularly Tier 2 and 3 suppliers. Likewise, charging infrastructure suppliers face financing constraints.

The financing challenge is also acute for service providers. India's bus and truck categories are dominated by the unorganised and small-scale operators. These players have limited owned capital and face barriers while accessing capital markets, including loans from the banking sector. Therefore, newer and flexible business models and financial instruments were considered essential. They need to be designed considering various technical and operational aspects, such as the need for battery replacement, lower operational costs, and lack of a secondary market.

At the retail level, access to loans has played a large role in enabling and driving the demand for vehicles in India. However, currently it is cheaper and easier for a customer to finance an ICE vehicle compared to an EV. Stakeholders felt that this will need to change to accelerate adoption of EVs.

5.3.5 Cost Disadvantages

Apart from industry-specific challenges, ecosystem barriers impact competitiveness of the industry. Factor prices such as land and labour are key inputs, as is the availability and cost of utilities. Further, regulatory cost and logistics challenges also influence the outcome. For instance, in the auto-electronics segment, compared to China and Vietnam, manufacturers in India maybe at a cost disadvantage of 7.5-15% according to Grant Thornton (2023). According to a report by the World Bank (2021), logistics costs in India account for about 14% of GDP, significantly higher than China's 8%, but lower than Vietnam's 16%. Improvements in the recent years due to expansion of infrastructure, particularly roads and railways, is expected to have addressed this issue to some extent. Further progress is expected with implementation of the National Logistics Policy that aims to reduce this cost to at par with developed nations (Invest India, 2022).

The cost disadvantage can also be due to the higher cost of electricity compared to China and Vietnam. Efforts to improve the power sector through various initiatives have been ongoing. States undertaking power reforms are incentivised to reduce losses, improve quality of supply and upgrade skills, amongst others. Together with the efforts towards increasing renewable energy capacity and lowering of prices, these moves will likely enable rationalisation of power tariffs.

> *"Targetted segmental incentivisation will drive the development of underlying technologies and capabilities. This will lead to secular traction in the market and thus feedback into the component industry."*
>
> ***A Leading EV manufacturer during a stakeholder consultation workshop conducted by RTI***

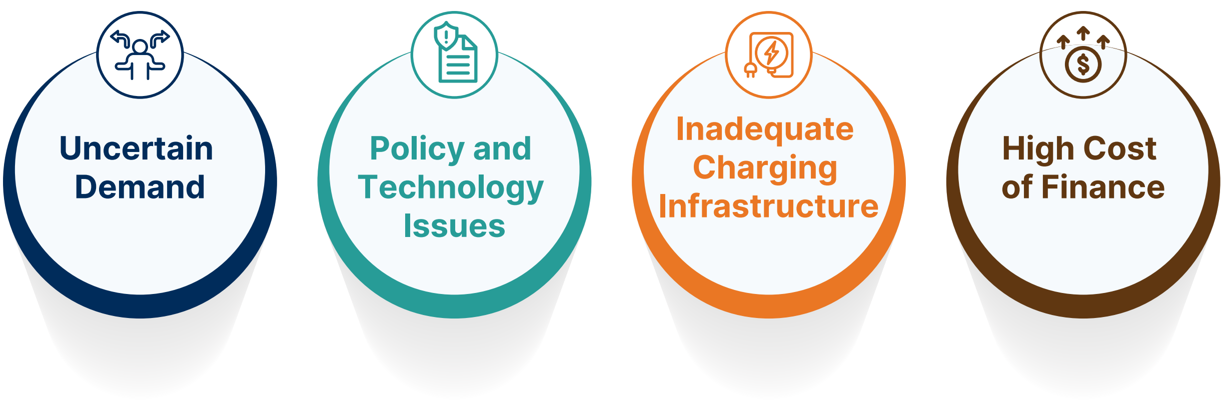
Broader efforts are also underway to reduce the cost of doing business. Several states have their own single-window clearance mechanisms, whilst a National Single Window Clearance system has also been setup. Further, many states have issued a state level e-mobility policy with a focus on expanding manufacturing. These policies typically provide fiscal and non-fiscal incentives for industries, thereby reducing the overall cost as well as cost of doing business.

In India, auto-clusters have played a crucial role in the development of the industry. The cluster approach, when effectively implemented, has a potential to address some of the cost disadvantages. Existing auto-clusters in India can be leveraged to spur domestic manufacturing of EV components. The Government can take the lead in earmarking additional land around these hubs, enable on-demand plug and play utility architecture, and encourage shared infrastructure such as testing, workshops, skilling, and tool sharing facilities for MSME to leverage (NITI Aayog and BCG, 2022).

5.4 Demand Side Analysis and Barriers

The growth of EV sales has been robust over the last five years. As discussed in Chapter 2 presenting market trends, 5 years CAGR across categories has been in excess 40% across segments. While the base is currently low, penetration levels are starting to exceed 5% in some of the segments such as 2W and 3W. While incentives offered by Governments have been a strong driver, there is also increasing self-interest as cost of ownership has declined rapidly. Further, there is increasing interest in buying EVs, particularly in the youth, compared to a few years ago.

Figure 5.6: Demand-side barriers



Source: RTI

Nevertheless, primary interactions with industry experts pointed to uncertain demand or low volumes as a binding constraint to expand domestic manufacturing. While many players have announced investments, these are generally in form of statement of intent. Many are in a wait and watch mode and there is a general reluctance to invest large amounts in the manufacturing ecosystem because of uncertainty of the demand. Other barriers on the demand side include inadequate charging infrastructure as well as challenges to accessing loans at a reasonable price. These challenges are depicted in Figure 5.6 and briefly discussed.

5.4.1 Uncertain Demand

The total cost of ownership (TCO) is a critical enabler for long term sustainable adoption of EVs. According to a report by NITI Aayog & ADB (2022), the total cost of ownership (TCO) parity has been achieved for a range of use-cases in 2W and 3W. Increasing demand in these segments corroborates the analysis and likewise localisation is high and increasing. TCO parity in other cases is still to be commercial demonstrated particularly for heavier vehicles such as trucks and buses. Therefore, there is a continuing demand uncertainty in these segments. Even where TCO parity can be demonstrated, other concerns such as higher acquisition cost of EVs, relatively expensive financing cost, lack of charging infrastructure, and mindset barriers, present significant barriers.

Under the FAME II scheme, E-Buses tender demonstrated that it was possible to achieve TCO parity in intra-city and short distance routes. This was facilitated by demand aggregation and initial enthusiasm in the market (CESL, 2023).

This success of CESL first tender enabled aggregation of demand from several cities, driving down the TCO and demonstrated a possible way forward. The bidding process concluded in April 2022 for 5,450 electric buses to be deployed in five cities across India (Delhi, Kolkata, Bengaluru, Hyderabad, and Surat). The Grand Challenge (GC) method delivered prices that were 23-27% lower than diesel or CNG buses, without existing subsidies. With the subsidies on offer, discovered prices were up to a third lower than ICE buses.

Costs were driven down owing to a variety of factors. First, there was homogenisation and aggregation of demand, lowering costs. Second, a fixed ten-year contract tenure, with an option of two more years was introduced, to maximise return on investments. Other terms included variable cost benchmarking, payment for unutilised and excess kms, and annual fixed escalation. Availability of land and civil infrastructure (such as electricity connections) were made the responsibility of the city. These changes from earlier approaches made the tender a more attractive proposition for private players to get involved (CESL, 2023). While it was demonstrated that it was possible for e-buses to compete on TCO basis, scaling has been a challenge as has been the case of inter-city transportation.

The subsequent tender floated by CESL in January 2023 was cancelled in August 2023. The primary concern for operators/OEMs centred around the surety of cash flows. Given past issues with delays in payments, and weak financial position of state transport undertakings (STUs), the lack of a payment security mechanism (PSM) emerged as the key concern (PIB, 2023). This is a big concern since the adoption of E-Buses will likely be driven by the public sector, at least in the near term.

To address these concerns, in August 2023, the Government of India introduced the PM E-Bus Sewa Scheme, which seeks to add 10,000 E-Buses to city fleets within a period of ten years. Under the guidelines of the scheme issued by the Ministry of Housing and Urban Development (MoHUA), state guarantees would be made for payment of bus operations, and that state governments would agree to the payment security mechanism being developed by the Government of India (MoHUA, 2023). In June 2023, a PSM for E-Buses was mentioned in the India-US Government Joint Statement, with the United States government committing $150

Million as a grant for this PSM. The MHI proposed a PSM like the one for solar energy implemented by the Solar Energy Corporation of India (SECI), which provides a three-month payment security to operators (PIB, 2022). The revised tender was released early in 2024 by CESL and was awarded recently for two states with a total of approximately 1400 E-buses. While competitive relatively small number of E-buses could be procured because TCO in some cases was higher, though not uncompetitive with diesel. However, procurement may have been limited because of other after considerations such as relatively small difference in TCO with other diesel or CNG buses, lack of charging infrastructure and the fact that the PSM mechanism was still to be finalized.

Increasing adoption of E-buses in the longer term will require addressing issues relating to operational and financial performance of the public transport authorities (PTAs). In the medium to long-term, reform of PTAs making them financially self-sufficient is the desired solution. This would improve creditworthiness of PTAs, enhance demand and reduce costs.

Another aspect is that the market for inter-city bus routes is much larger compared to the intra city one. According to the Ministry of Heavy Industries (MHI), about 90 (PTAs) operate 150,000 buses in India. Most of these buses serve inter-city routes, while 18% or 27,000 buses operate within cities (PIB, 2023). This implies, that close to 80% of the market for buses is for inter-city travel. Furthermore, in terms of fleet size, the private sector constitutes a 93% share in all registered buses in India, with public sector having a relatively small share of 7% (MoRTH, 2023b). The total number of buses in India have been estimated to be approximately 2.0 million by MoRTH (MoRTH, 2020).

The transition to E-Buses will therefore depend on making inter-city routes more viable, along with demand-side incentives for private players. There is limited experience till date of operating E-buses though some companies such as Nuego are operating on routes such as Jaipur-Delhi-Agra etc. However no technical or financial data in public domain to assess their viability, competitiveness or customer experience.

Inter-city routes do offer advantages such as being more amenable to stops in journeys. For instance, inter-city buses regularly make at least one-scheduled stop on highways. Other inter-city buses may also traverse through bus depots of cities along the way. This implies that inter-city bus routes, if planned optimally can swap batteries or charge at scheduled stops and pickups. The same can be applied in case of trucks, which also have night stops in many cases. In other cases, long-stops to recharge vehicles are not practical and can be unattractive for most users. Therefore, for heavier vehicles, an expansion of fast charging infrastructure along highways is critical for transition.

A similar narrative applies to trucks. According to the MoRTH (2023b), approximately 5.8 Million trucks and lorries are registered in the country. According to NRDC (2023), close to half of the trucks are owned by individuals, and 70% of the market consists of small fleet operators. Furthermore, an analysis by NITI Aayog and RMI (2022) reveals that the upfront cost of an electric truck is 2-6 times that of a diesel one, and the payback periods could be in the range of 6 – 18 years.

These factors will likely result in slow penetration, unless specifically addressed. Uncertainty in the demand for heavier e-vehicles is a result of structural factors i.e., nature of the market, socio-political considerations, and state of the technology. Dedicated efforts will be required to address these, across all stakeholders. Availability of competing technologies and fuel options, along with a competitive landscape means that uncertainty w.r.t. EVs will continue to prevail particularly for heavier segments.

While incentives and indicative targets have been established to drive e-mobility transition, specific regulations or mandates have not been. Mandates with sale targets for EVs have however been used in other parts of the world (NRDC & ASCI, 2023). For instance, in China, EV targets as a percentage of sales were established, creating a 'dual credit' system where businesses receive credits for new energy vehicle (NEV) sales and fuel efficiency improvements. Shenzhen for instance, has achieved 100% electrification of their public transport fleet.

In other countries as well, fleet electrification targets have been actively deployed by governments. The state of California has mandated all ride-hailing services to be 90% electric by 2030. Several other states in the United States have mandated the full electrification of government vehicles (NITI Aayog and BCG, 2022). Cities in India, especially with high levels of air pollution should consider adopting carrot and stick approach for improving air quality by accelerating e-mobility transition.

Emission norms have been another tool utilised by national and sub-national governments to drive electrification. The use of feebates, where additional levies on ICE vehicles go towards incentives for zero-emission vehicles (NITI Aayog, RMI, 2022) is one such option. Mandates and electrification targets are important from a demand signalling perspective, especially for creating demand in the short to medium term. Further, mandates, when used in tandem with supply-side policies, are likely to spur creation of a robust domestic manufacturing ecosystem.

5.4.2 Policy and Technology Issues

As noted in Chapter 2, large investments are planned by OEMs and component manufacturers to enable e-mobility transition. A need for comprehensive vision or overarching policy was also mentioned in section 5.3.1. From the demand side perspective, the need for such a policy is relevant given the multiple technological options and to address consumer mindset barriers.

India's ambitious climate goals, rapid urbanisation and a growing population, means that the achievement of net zero by 2070 will require a multifaceted strategy to decarbonise the transport sector. This is the reason that the government appears to be pursuing a multi-pronged strategy.

Decarbonisation will require electrification of segments wherever possible; transition to sustainable fuels where electrification is difficult, and potential adoption of hydrogen-based fuels in some segments. Government policies, programs and initiatives are therefore supportive of multiple technologies and cleaner fuels. While desirable from the society's perspective, this approach creates some uncertainty and risks for OEMs and component manufacturers and therefore, acts as a damper to large investments essential to accelerate EV adoption.

While India has implemented the Bharat Series standards, BS-VI being the most recent one, to regulate emissions, these are yet to be fully adopted, especially for heavier vehicle segments. Therefore, gaps in regulations and standards acts as a barrier for adoption of e-vehicles. However, it is understood that BS-VII norms are likely to be implemented soon, potentially by 2025. Likewise, Corporate Average Fuel Efficiency (CAFÉ) norms applicable to carmakers are likely to be tightened over time. These developments will enhance the appeal of EVs and cleaner technologies. Some of the alternative fuels and technologies in transport being pursued by stakeholders are briefly descried below.

a) Hybrids

Hybrids are powered by two sources – an ICE engine, combined with a battery and an electric motor. These are emerging as a serious contender to EVs. As per the VAHAN database, sale of hybrid cars (3.3 lakh) significantly exceeded EV cars (0.73 lakh) in 2023. Hybrid cars are costlier than EVs owing to various factors including higher GST rate. Increasing sale of hybrids is not expected to impact EV components significantly as they also require most of the components needed to operate EVs.

b) Hydrogen-based Transport

Hydrogen based vehicles are at the research, development, and demonstration (RD&D) stage. Various OEMs such as Volvo Eicher Commercial Vehicles (VECV), Ashok Leyland, Tata Motors, and

Cummins are working on a hydrogen IC engine development for heavy commercial vehicles. Some have also demonstrated hydrogen fuel based four wheelers. Fuel cell vehicles have inherent advantages in terms of longer driving ranges, faster refueling time, efficiency in operations and eco-friendliness (water is the only by product). Top 3 OEMs (Ashok Leyland, Tata Motors, and Eicher) in the country are currently working on developing hydrogen fuel cell vehicles under the PLI auto scheme. Therefore, there is serious interest in commercialisation of this technology, especially for heavier vehicles. However, despite evident advantages and OEMs' interest, there is uncertainty due to lack of required infrastructure, storage challenges and cost disadvantages. Further, due to safety and other issues, hydrogen may not be a viable candidate for the light duty vehicles segment due to size and weight limitations (AFDC, 2024). It is however likely to emerge as a strong contender for heavy vehicles, such as long range inter city buses or trucks in medium to long term.

c) Ethanol

There is a significant policy push for ethanol by the central government with a target of blending 20% ethanol in petrol (E20) by 2025/26 (NITI Aayog, 2021). The policy aims to roll out E20 material-compliant and E10 engine-tuned vehicles from April 2023. It also proposes to provide tax incentives for E10 and E20 fuels to compensate for the drop in efficiency due to blending ethanol. Most OEMs are prepared for this transition and are awaiting further details. Enabling this transition would not require significant changes to the assembly line and additional components required can be manufactured locally. This can potentially impact EV sales, most likely of 2W, 3W, and cars.

d) CNG and LNG

India has a history of over 30 years in developing and using cleaner fuels. The first exhaust emission standards were published in 1991, and by 1993, Delhi had established three stations for dispensing compressed natural gas (CNG). In 1998, the Supreme Court of India (SC) ruled that all busses, three-wheelers, and taxis in Delhi to operate using CNG. SC's ruling also specified an increase in the number of CNG refuelling stations and financial incentives for the conversion of fleets.

Under the Petroleum and Natural Gas Regulatory Board (PNGRB) Act 2006, PNGRB grants authorisation to entities for developing a City Gas Distribution (CGD) network. CNG as auto-fuel, Piped Natural Gas (PNG) for domestic, commercial, and industrial use, are the main customer segments. Companies like Indraprastha Gas Ltd, Mahanagar Gas Ltd, Gujarat Gas, Adani Total, Torrent etc. are involved in CGD network development. With a potential to serve over 70 percent of the population, an investment of INR 120,000 Crore is expected over the next 10 years towards expansion of this networks in 407 districts across the country (MoPGN, n.d.).

CNG adoption can pick up significantly if incentives are offered by Government or low prices are maintained by licensees to enhance sales and viability of their network. Further, in case new products are launched, such as the Bajaj Freedom motorcycle launched recently (Bajaj Auto, 2024), it possible that some consumers may prefer them over EVs. Such a scenario can negatively impact EV sales and components.

5.4.3 Inadequate Charging Infrastructure

A review of literature reveals that consumers continued to be concerned about the range, colloquially known as 'range anxiety'. This is a greater concern in commercial use-cases. While charging may be possible at home in some cases, wide-spread availability of public charging infrastructure remains a constraint. The Ministry of Power has recommended an EV charging station for 3km x 3km grid in urban areas. On National Highways, one charging station is recommended at every 100 km on both sides, and one fast charger every 25 km, on both sides. According to a Parliamentary Standing Committee report published by the Rajya Sabha Secretariat

> *"Rather than increasing charging infrastructure, we should also look to focus on alternate technologies which are completely indigenous and do not require such large scale investment in infrastructure."*
>
> ***A Leading EV manufacturer during a stakeholder consultation workshop conducted by RTI***

(2023), against a target of 22,000 public charging stations under the FAME II scheme, only 7,432 charging stations have been sanctioned.

In urban areas, the availability of land is an inhibiting factor. Land rents or leases are usually quite expensive. Coupled with the initial investments in chargers, the total costs often outweigh revenues in the initial years. As demand ramps up, private owned charging stations will become more competitive. However, at present, the cost economics is proving unfavourable. It was also noted that a significant proportion of chargers are slow chargers and further, a significant number were not functional on any given day due to a variety of issues.

Under the FAME II, the subsidy for charging stations is provided only for the public sector. Whereas in the case of EVs, the subsidy is provided to both public and private sectors. Some stakeholders suggested that support to private sector should also be provided.

5.4.4 Higher Cost of Finance

Access to finance in the form of a personal loan plays a role in driving demand for vehicles in India. However, currently it is cheaper for a customer to finance an ICE vehicle as compared to an EV. According to a report by NITI Aayog and Boston Consulting Group (BCG) (2022), interest rates on EV loans can be 1-9 percentage points higher, with shorter tenures, and smaller loan-to-value (LTV) ratios. Higher spreads appear in the case of 2W and 3W in comparison to 4W. This point was raised by stakeholders during the industry consultations as a significant barrier to adoption of EVs.

It was noted that these concerns suggest a higher risk perception of EVs over ICE vehicles by the financial institutions. Lack of a secondary market in EVs, for both vehicles and batteries, is one of the factors leading to higher cost of finance. An ecosystem around battery recycling and reuse is yet to be established (NITI Aayog and Green Growth Equity Fund Technical Cooperation Facility, 2022). A market for used batteries would help drive EV adoption and help allay the concerns of FIs (NITI Aayog & ADB, 2022). Furthermore, in the case of heavy vehicles, the risk of competing technologies such as the use of hydrogen further raises the risk perception. Buyback programmes and extended warranties by OEMs can help in reducing the risk perception of EVs.

5.5 Action Roadmap

This analysis, basis triangulation of data, collected from primary as well as secondary sources, views expressed by senior industry experts, and international experience, suggests that accelerating localisation of manufacturing will require intervention on both demand and supply sides. Addressing challenges on both ends will need to involve all stakeholders including government, private sector, researchers, academia, and other stakeholders. While the government will need to focus on creating an enabling environment, investments will need to be made primarily by the private sector.

Therefore, the proposed action-plan is presented in two categories, i.e., first the supply side interventions - those intended to directly boost domestic manufacturing, and second the demand side interventions- those targeted to enhance certainty of demand by accelerating adoption of EVs. A virtuous cycle, with interventions on both, i.e., the demand and the supply side will be aligned to the progressive and transformative scenarios.

Further, proposed actions are presented for short to medium term and separately for the long-term actions. Short and medium-term actions are defined as actions that can be taken in the next few years. Long-term actions are expected to begin now but will take time to evolve and get implemented over a 5-10- year horizon.

5.5.1 Supply Side Proposals (Short to Medium Term)

Based on the analysis in the previous section, supply side interventions are proposed in five distinct areas as outlined below. Short to medium term actions are detailed here and several of them will likely have a bearing on the future, even in the long term. It is noted that additional policy initiatives are likely to be undertaken post formation of the new government.

a) Policy Enablers

The domestic ecosystem is still evolving, and the industry feedback suggests that it needs to be further encouraged and supported. The need for continued support is evident from the fact that most industry participants felt that increasing localization in the short term will remain challenging. It is also the case based on evidence from the PLI scheme, which suggests that the process will require more time than initially anticipated. Three areas are particularly important in the policy domain from the perspective of immediate attention – design of a National Clean Mobility Policy, PLI schemes and GST structure.

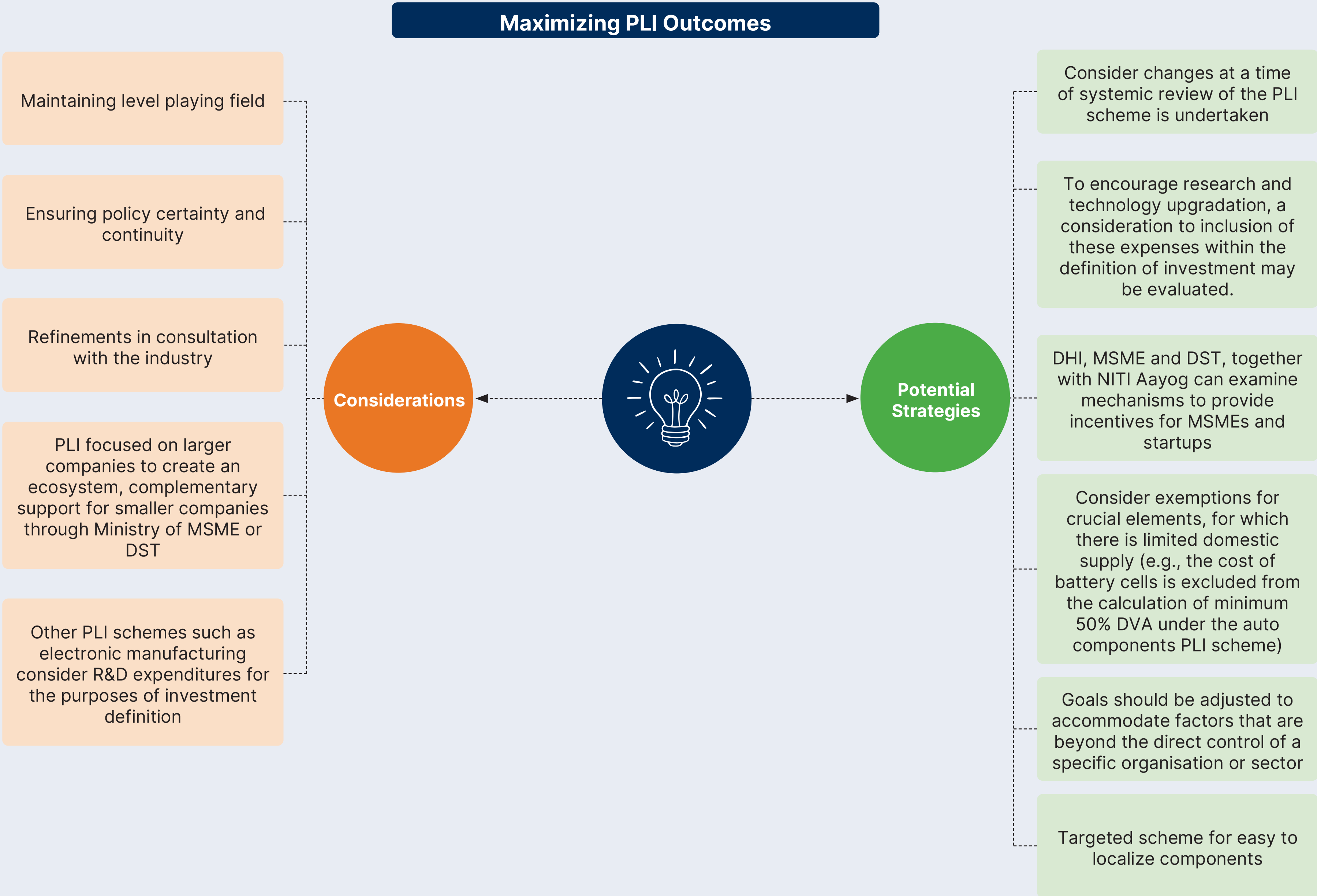
As mentioned, there is a considerable uncertainty in the global and domestic ecosystem, given the current and emerging challenges. These uncertainties create risks for investments. It is evident that e-mobility transition and localisation will require significant investments in various parts of the value chain. Many industry stakeholders expressed concern relating to uncertainty in the market with respect to demand, technology, and financing. These risks delay investments and increase the cost for businesses. Therefore, it is relevant to consider developing a National Clean Mobility Policy and Plan to provide a broad vision for transition, keeping in consideration various aspects such as improving urban air quality, generating livelihoods, enhancing energy security, amongst others. Such a policy will provide clarity and certainty to not only the industry but also to consumers and thereby encourage adoption. Therefore, a mention of this policy is also made in the demand side interventions.

PLI schemes provide necessary and desirable support to accelerate domestic manufacturing. As mentioned, some refinements and adjustments will enable better outcomes (Figure 5.7)". It is recommended that changes may be initiated and implemented in consultation with the stakeholders, particularly industry. It is noted here that PLI schemes were designed to attract large investments and focused on organized sector to create champions in the respective sectors. Further, there are certain limitations to making changes to a scheme which was launched a few years ago.

Recognizing these considerations and sensitivities, the recommendation to introduce changes is made with certain caveats. A key limitation to making changes is the need to ensure and maintain a level playing field i.e., any amendment which will benefit one or small group of companies is not desirable. Further, it is critical to ensure policy certainty and continuity. Therefore, changes must not compromise or create an impression of sudden policy shift. Therefore, one option is to consider changes at a time when systemic review of the PLI scheme is undertaken. It is understood that Government periodically reviews all schemes to evaluate progress and consider stakeholder inputs. Such a process may provide an opportunity to incorporate amendments, in consultation with the industry as well as to rationalise schemes across various sectors.

Another option is to incorporate a separate scheme. This maybe particularly after relevant for example as a mechanism to incentivise start-ups and MSMEs since they constitute a significant part of the value chain. A new scheme

Figure 5.7 : PLI scheme: Potential Strategies



Source : RTI

will provide an opportunity to design it to suit their specific needs, ensure continued focus on creating champions under the PLI and if desired, can be broader and administered by a different department, such as the Ministry of Micro, Small & Medium Enterprises.

Since the PLI focused on larger companies with an intent to create an ecosystem, complementary support for smaller companies is possible through ongoing schemes of Ministry of Micro, Small and Medium Enterprises or Department of Science and Technology. However, given the large size of the opportunity in the automobile sector, it is recommended that DHI, MSME and DST, together with NITI Aayog consider mechanisms to provide incentives for MSMEs and startups in the sector. Such a mechanism will be intended to provide support complementary and in co-ordination with the PLI scheme for large companies.

Since R&D investments remain low, it is suggested that whenever a review of the PLI scheme is undertaken, a proposal to consider R&D expenses and the cost of technology acquisition within the definition of investment maybe evaluated for inclusion in the PLI scheme. As already noted, most companies in the sector spend less than desired level on R&D initiatives. Further, several new technologies are not domestically available. It is also noted that the investment requirements are sufficiently high and some of the other PLI schemes such as electronic manufacturing consider these expenditures for the purposes of investment definition. Therefore, it is recommended that to encourage research and technology upgradation, a consideration to inclusion of these expenses within the definition of investment may be evaluated.

The feedback from stakeholders suggests that DVA targets may need more time to be achieved given the significant investment requirement. This is considering that such investments take time to mature. Many industry stakeholders conveyed that the DVA targets under the auto PLI scheme are ambitios and more challenging compared to other PLI schemes, such as the one for electronic components. At present, a few exemptions such as the cost of battery cells is allowed to be excluded from the calculation of minimum 50% DVA under the auto components PLI scheme. These exemptions are co-terminus with the PLI scheme for advanced chemistry cell batteries. Considering similar exemptions for crucial elements, i.e., those for which there is limited domestic supply will enable better outcomes under the PLI scheme.

Ambitious goals are generally considered desirable, but they need to be adjusted to accommodate for factors that are beyond the direct control of a specific organisation or sector. These include, for example, development of ecosystem, uptick in demand, and continuing infrastructure constraints. DVA targets were previously adjusted in December 2023, and it is suggested that these maybe revisited at time of systematic review of the PLI scheme.

When reevaluating the scheme, it is also possible to consider a different approach i.e., to consider adopting a different matrix i.e., aggregate value addition by a sector to the economy, instead of domestic value addition by an organisation. Such an approach is premised on the rationale that current volumes are low to justify new investments and that in the long run, aggregate value addition will lead to an increase in DVA. Further, economic literature suggests that the value added of exports in an economy can be greater than the strict value of exports due to additional production-to-consumption impacts beyond the foreign exchange earnings. Evidence from China (Llop, 2024) points that such approach may have led to increased exports, enabling livelihood development, and increasing DVA overtime.

Targeted localisation based on existing domestic capabilities can be adopted as another alternative strategy to accelerate localisation. Capabilities to manufacture some of the components and sub-components already exists and, in a few cases, these are already being supplied. However, there are concerns related to quality and cost. Examples include motors and sub-assemblies such as copper windings, lamination PCBs, Hall

Effect sensors, etc. A sub-category within the PLI scheme, at time of a systematic review, for enhancing localisation of such components may be considered as it is likely to yield faster results. An alternative option is to consider separate PLI scheme for such components. Such an initiative can be undertaken by allocating additional funding or by utilizing unused funds from the ongoing scheme.

Other than PLI, the GST is a vexing issue, particularly for the before smaller companies i.e., Tier 2/3 players, start-ups and MSMEs. This relates to the before inverted GST structure between the product i.e., EVs versus that applicable on the components. GST on EVs is 5% and is considered desirable to accelerate adoption. However, components are taxed between 18%-28% and this results in working capital crunch and reduces profitability (Deolekar & Tiwari, 2024). For smaller companies, resolving GST issues such as litigation and arranging alternative working capital can absorb significant amount of management time and is counter-productive to the focus on localisation.

Modifying the inverted GST structure can be initiated by the GST Council, and it is recommended that this may be considered at the earliest. Proposal for in front of modification of inverted GST structure has been undertaken previously by the GST for various sectors. It is therefore considered to be a relatively change after easier, even though it requires engaging multiple stakeholders.

While the above issues with have been highlighted, it is imperative that the localisation of components and sub-components should be considered in the broader context of trade and industrial policies. An assessment of localisation mandates, together with trade data at the 8-digit level, along with import duties, can provide useful input to inform decision making.

b) Addressing Skill Gaps

As outlined above, there is consistent feedback on inadequate availability of trained manpower, both engineers as well as technicians.

Some existing academic institutes have created EV specific courses as part of their degree programmes. These include some of the leading institutions such as the before IIT Madras as well as those in the private sector such as the before Symbiosis Institute of Technology. However, a lot more needs to be done, especially to develop and enhance the knowledge base.

An important suggestion is to mandate specialised EV courses in streams such as electronics, electrical, mechanical, and industrial and institutions such as ASDC, AICTE and NCVT to take lead in this initiative. Areas of identified after focus based on this analysis and feedback from industry include mechatronics, simulation tools, and embedded software development. Strong capabilities in motor design as well as specialisation in power electronics at degree and doctorate levels are also suggested. Further, the courses should be designed to fulfil practical requirements that can serve basic and advanced level needs of various stakeholders. At post graduate level, one full semester should be dedicated to internships in the industry to enable industry-academia collaboration in higher education and research.

There is a need to encourage partnerships between the industry and academia to ensure that curricula and industry requirements are in consonance. Symbiosis Institute of Technology is an example of one such partnership where several industries have come together to develop high quality infrastructure such as labs and collaboration with relevant stakeholders such as ARAI.

Online courses on edtech platforms have also been launched with some courses being open source while others being paid. These paid courses offer certifications, providing opportunities for professionals to upskill and reskill themselves. These existing courses and platforms can be leveraged to create a virtual Power Electronic Machine and Drives Skills Platform. This platform can aggregate and provide open-source learning tools, industry certified courses at nominal costs, and a dedicated employer-employee matching platform.

To attract talent, there is a need to develop internship and apprenticeship programmes and design integrated learning programmes. OEMs and Tier 1 manufacturers should be encouraged to recruit from campuses, to boost attractiveness of these courses for prospective students, and build a pipeline of skilled manpower.

On the skilling front, the effort should be industry led, where the government can consider providing limited financial assistance through targeted apprenticeship, training, and upskilling programs. These programs need to be cost-effective and will create an impact over a period of time.

It is suggested that the private sector partners work with the government in aggregating demand for training, apprenticeships, and upskilling (ACMA & YES Bank, 2021). There is a need to shift training and thinking from standalone disciplines such as mechanical, electrical and electronics to cross-sectoral themes. Further, it is relevant to develop an understanding of software across disciplines given the technological evolution.

This training and upskilling must not be limited to the shop floor; the industry should come together to upskill mechanics and technicians in the broader ecosystem comprising dealerships, service centres as well as recyclers.

Some of the key themes to focus on include electrical safety precautions, auto electrics and electronics, training in required hand-tools and machines, amongst others (KPMG, 2023). Industry should lead the development of these courses, leveraging existing information as maybe available from stakeholders such as the Automotive Skill Development Council (ASDC). These programs can be delivered through government industrial training institutes (ITIs) and skilling institutes as well as can be made available to private institutions.

An additional suggestion for consideration is to allow CSR funding for developing open access laboratories, facilities and content for capacity development. Corporates in the sector can fund common centres that can be established in reputed academic institutions and will be used to enhance skills in the sector. Any academic and training programs offered by these centres will be accessible by any company on pari passu basis.

c) Investing in R&D and testing

As noted previously, investments in R&D in India are well below international averages. With a favourable policy environment, OEMs in India's auto industry must invest in R&D and create intellectual property to build competitiveness. In the Interim Budget Speech of 2024, a corpus of Rs. 1 lakh Crore was announced to boost R&D investments in India. To be made available as 50-year interest free loans, this corpus provides an avenue for the industry to raise R&D investments in partnership with startups and academia.

R&D efforts usually require a longer time frame to yield results. Therefore, it is important to develop long term roadmap and strategy for R&D in the automobile sector, particularly considering the e-mobility transition. The Department of Science and Technology recently produced a detailed and well researched report listing the priority areas and framework for catalysing technology led ecosystem for e-mobility transition (DST, 2024). It is suggested that an industry led task force maybe constituted to detail specific next steps, including investments needed, timelines and monitoring of activities.

Another area of focus is to create an industry benchmark facility for EV motor and PE development. An example of such an approach is the Winding Centre of Excellence Warwick Manufacturing Group (WMG) in the UK. The government funded the initial capital required for machines and tools, to the tune of GBP 4 Million. This allows companies to utilise the equipment to run their own testing, prototyping, and undertaking small scale manufacturing. It is an innovative way to reduce the financial risk in innovation. Since several leading institutions such as IITs have operationalised Centres of Excellence (refer Figure 5.8 for list) on various EV related aspects, these existing initiatives can be leveraged to create a network of institutions, which can help drive R&D, testing, and prototyping.

Figure 5.8: Dedicated EV centres in academic institutions

Institute	Centre of Excellence for Electric Vehicle	Year Established	Research Areas and core objectives
IIT Delhi	The Centre for Automotive Research and Tribology (CART)	2019	Battery technology, motor technology, power electronics and charging solutions.
IIT Bombay	Dedicated center for Sustainable Transportation		R&D in Battery technology, motor technology, and charging infrastructure.
IIT Madras	Centre for Battery Engineering and Electric Vehicles (CBEEV)	2016	Electric Vehicles and EV subsystems, Battery Engineering and management, Chargers and Controllers.
IISc Bangalore	Dedicated centre for electric power and energy systems		Innovating for Transport and Energy Systems (ITES): India-UK collaboration. Research on battery technology, motor technology, and charging infrastructure.
SRM Institute of Science and Technology	The Electric Mobility (E-Mobility) Research Laboratory (EMRL)	2019-20	EV integration and technology services, Electric Vehicle Power System integration, Simulation, Motor control, EV chargers and battery management systems.
Symbiosis Pune	Bajaj Engineering Skills Training - E-Mobility Lab, dedicated trainings and tie-up with industry players		Bajaj Engineering Skills Training Initiative: Showcasing hands-on training at the Bajaj Training Center in SIT Pune. ARAI collaboration to enhance technical education.

Source: RTI Analysis

From a localisation perspective, it is suggested that some of these Centres of Excellence are expanded with industry leadership, catalysed by bodies such as CII, SIAM, ACMA etc. Three specific areas of focus with significant relevance from EV perspective, but also wider automobile, electronics and IT sector are:

1. Traction Motors and controllers, particularly for larger vehicles. Some of the recommended components are – REE free permanent magnets, enhancing efficiency of motors (SynRM and IM) via design and optimization of sub-components), introducing circularity in design and manufacturing, particularly for copper, steel, magnets and aluminum.
2. Power Electronics with focus on high voltage inverters, controllers and OBCs. In semiconductor domain, research areas include wide band gap semiconductors to improve yield, and performance optimization for Indian conditions.
3. Automotive software to optimise vehicle performance.

Developing shared facilities for testing EV motors in automotive clusters, as being done in Coimbatore, can be replicated by the state governments with major automobile hubs such as Haryana, Gujarat, and Maharashtra. The state governments can partner with the central government in acquiring bulk licenses for simulation tools and platforms, facilitating access for MSMEs and startups. Under the design linked incentive scheme of the India Semiconductor Mission, the government acquires licenses for electronic design automation (EDA) software tools.

To promote circularity and achieve sustainability in electric motors, the design of the motor itself may need to be re-evaluated. An effort towards standardisation of some of the key sub-components and modularisation of motor maybe considered as an industry agenda to enable easy disassembly at the EOL of the motor. This way, the resources are retained within tight loops via reuse, repair and remanufacture. Countries such as the US and UK have devised roadmaps and targets for factors such as the cost and power-density of motors. This has enabled the development of a clear and driven research agenda. Working together with the industry, a similar exercise should be undertaken in India, where cost and power-density targets are defined for the medium to long term.

Another option is to establish a dedicated patent fund that can enable Indian companies, particularly small and medium ones to access global patented technologies and support localisation efforts.

A related aspect to R&D is the expansion of testing facilities. While some facilities have been established as previously mentioned, there is a need for significant expansion to enable testing efficiently and at reasonable costs. It is recommended that the government should enable establishment of testing centres in an open access mode as collaboration between industry and academia. Such centres in and around auto clusters will accelerate research, design and development of EVs.

Some leading component suppliers have already established their own testing facilities incurring large investments. It is also possible that they may make them available to other manufacturers for testing.

While these are large investments, they may diminish with development of technical expertise and learning curve. It is therefore relevant that they are developed as public facilities or as joint facilities to reduce the burden on individual industry players, especially start-ups and smaller companies. Similar to the recommendation for training and capacity development, it is suggested that CSR funding maybe allowed to be utilized for developing common facilities in open-access mode for use by all on pari-passu basis.

d) Unlocking Access to Finance

Manufacturers, particularly smaller players, and startups face a constraint in accessing finance. Credit guarantee schemes launched for MSMEs in the past have seen success, particularly during the COVID-19 pandemic. A dedicated credit guarantee scheme through institutions such as IIFCL, NIIF, etc. can be established to enable easier access particularly for start-ups and MSMEs in EV component supply chain (Singh, Chawla, and Jain, 2022). Such a fund could involve multilateral development banks (MDBs), impact investment funds, and philanthropic funds, for instance, who can either invest equity, provide grants, or subordinate debt. In turn, this fund can invest or lend to eligible EV auto component manufacturers and could also issue risk-sharing instruments, earning fees in return.

Additionally, banks should be encouraged to establish a low-cost working capital window for MSMEs in the EV space. Initiating dialogue with relevant stakeholders to create a fund to support MSMEs in technological upgradation through risk sharing facilities, or low-cost loans, amongst others should be undertaken, with a view to implement in the medium term.

Further, startups in EV can be encouraged and scaled through competitive grants that can be funded by DST or MSME. Centres of Excellence operated by IITs can serve as Project Implementation Agency for managing such schemes.

e) GVC Enablers

In order to enhance and accelerate localisation, Indian companies will need to be better integrated with global value chains. Such a transition is underway in manufacturing of mobile phones and has started in the automobile industry.

There are several steps that can be undertaken to improve overall environment for manufacturing. First, state EV policies can enable faster and easier land acquisition and infrastructure provision on a priority basis for e-mobility investments.

Second, Government of India's push to accelerate and encourage investments that reduce logistics and infrastructure costs needs to be continued and enhanced. Some areas that require attention include power sector reforms to rationalise electricity tariffs, accelerating development of social infrastructure around automobile hubs, and faster implementation of Dedicated Freight Corridors for movement of goods.

Further, the overall regulatory and compliance burden on manufacturing needs to be reduced significantly to make the business viable and attractive. This is particularly relevant for small businesses and startups, but it will make India's manufacturing ecosystem more competitive across the value chain. The need is evident from anecdotal evidence of many small manufacturing businesses closing down and others shifting towards services such as trading (Economic Times, 2024).

In addition to the above, it is critical to establish and enhance policy cohesiveness across domains. These include industrial policies, trade policies, finance, FDI policy, R&D policy, standards, labour, and education policies (Figure 5.9). Such an approach will benefit all manufacturing and reduce cost of doing business. Under the Scheme to Promote Manufacturing of Electric Passenger Cars in India, OEMs will be able to import passenger vehicles at a reduced import rate, subject to a minimum investment of Rs. 4,150 Crores (USD 500 Million). This scheme is expected to spur the manufacturing of passenger EVs in India. As the larger green mobility transition is in heavy vehicles segment, such as buses and trucks, similar schemes may be considered for heavy vehicles as well. These would have the effect of increasing domestic model availability in the short-term, while also establishing world-class manufacturing facilities that are ready to serve export markets and boost foreign direct investment.

A summary of proposed interventions along with key stakeholders is presented in Figure 5.10.

Figure 5.9: Policy enablers to improve Indian industry's integration with global value chains

Source: RTI Analysis

Figure 5.10: Proposed Supply Side (Short to Medium term) interventions

Interventions	Government	Industry	Academic Institutions	Financial Institutions
Policy Enablers				
Develop a National Clean Mobility Policy and Plan with a long-term perspective	MHI, NITI Aayog	Industry Associations	Various, Also Customer groups, thinktanks, NGOs	Various
PLI scheme review and adjustment in consultation with industry to enhance outcomes.	MHI	Industry Associations		
Remove inverted GST structure	MHI, GST Council			
Access to Finance				
Create a risk guarantee fund for Tier2/3/ MSMEs	MSME, MoF			IIFCL, SIDBI and others
Create a competitive grant fund for EV start-ups, CSR funding is one option.	DST, MSME		Existing CoEs	
R&D				
Long term technological roadmap, in consultation with the industry	DST	Industry Associations	IITs, IISc. NITs	
Establish Centres of Manufacturing Excellence Traction Motors and controllers Power Electronics Automotive software		OEMs, Industry Associations	CoEs, other academic institutions	
Encourage collaboration across auto-electronics-software as well as auto-finance-insurance companies		OEMs | Software companies Industry Associations	CoEs, other academic institutions	Banks
Develop shared testing facilities in automotive clusters		OEMs	CoEs, other academic institutions	
Consider standardization and modularization in motor design and other components		OEMs Industry Associations	CoEs, other academic institutions	
Upskilling Labour Force				
Design specialised courses (Mechatronics, Simulation tools, Embedded software development)		OEMs	ASDC, AICTE, NCVT and others	
Create internship, apprenticeship, and recruitment programmes at institutes with specialised EV courses		OEMs | Tier 1|MSME and startups	Universities | Colleges	Banks
Develop a virtual Power Electronic Machines and Drives (PEMD) Skills Centre		OEMs	IITs, NITs, CoEs	
Create designated Skilling Centers in ITIs and vocational institutes in partnership with OEMs	State Governments	OEMs	ASDC, NCVT and others	
GVC Enablers				
Structural reform to accelerate and encourage investments in manufacturing	NITI Aayog as focal point			
Easier land acquisition and infrastructure provision for manufacturing facilities	State Governments			
Rationalization of electricity tariffs	SERCs, State Governments MoP			
Acceleration of Dedicated Freight Corridors	DFCCIL, MoR			
Trade and Industrial Policies	MHI, MoC, MoF			

Source: RTI Analysis

5.5.2 Demand Side Proposals (Short to Medium Term)

Increased adoption of EVs is a function of policy environment, cost of ownership, the state of charging infrastructure, and the cost of finance.

a) Market Creation

In the short-term, actions will consist of demand incentivisation and aggregation, primarily led by the central and state governments.

For creating demand, a variety of fiscal and non-fiscal instruments can be deployed, depending on the context. Fiscal incentives could include offsetting costs through discounts, tax rebates on loans, and motor-vehicle tax exemptions (NITI Aayog & BCG, 2022). FAME II has been extended for a period of four months in the interim, and a new policy is expected soon after. The upcoming FAME III scheme needs to consider extending incentives for heavy vehicles to lower their upfront cost.

Given that TCO is lower for most use cases in 2W an 3W segments, it is suggested that a large proportion (about 50%) of incentives should be targeted to support heavier vehicles with particular emphasis on e-buses for public transport. While TCO for E-Buses is already competitive in many use cases, support is recommended because of other structural barriers such as large initial investment, poor financial health of PTAs, lack of adequate charging infrastructure and mindset barriers. Other fiscal incentives to boost adoption, especially for heavy vehicles could be lower toll rates, to further reduce operational expenses. For 2W and 3W segment, it is recommended that the current incentive in form of deduction available under Section 80 EEB of the Income Tax Act may be continued till a relatively high penetration, say 33%, is achieved.

Many state governments have been proactive in incentivising demand through state level policies, and it is suggested that they may be continued in the short-medium term, but a more coordinated approach may be adoptedFurther, expedited plans for transitioning government vehicles should form an integral part of state level policies.

Non-fiscal incentives could include aggregating demand to electrify government and PSU owned fleets of buses to provide an impetus to demand in the near term. While the PM E-Bus Sewa is continuing the electrification of buses, public transport projects should provide for assured payments and revenues. Further, it is recommended that state governments should initiate pilot projects on long distance bus routes, providing a demand impetus in the near term.

TCO for e-buses is already lower in many use cases as discussed earlier. With increased volume and spread of charging infrastructure, e-buses are expected to become increasingly attractive. In the short term, demand aggregation model can be expanded as it is working well and a PSM is underway. In the medium to long term, states should be encouraged to improve efficiency and customer centricity of state and city bus services. These measures combined with reducing TCOs is expected to make E-Buses increasingly attractive. Therefore, it is proposed that by 2026, voluntary targets for procurement of e-buses maybe adopted. It is possible to set a target of 50% of new buses to be electric by 2030, all new buses maybe electric in the coming decade. To complement the targets , it is suggested that some incentive may still be offered to overcome other barriers to adoption such as higher capital cost and inadequate charging infrastructure. One option is to provide accelerated depreciation for e-buses in conjunction with the mandate. The current depreciation rate on buses is 30% irrespective of technology. E-buses can be offered a higher depreciation rate (say 40%-50%) for some years to accelerate the transition.

Further, newer business models such as the ones including leasing and transport as a service should be encouraged to be adopted by the private sector to boost demand. App-based monitoring and geofencing are additional avenues to pursue (B&C, 2023).

In case of trucks, some fiscal incentives through FAME III, particularly for LCVs, maybe offered along with non-fiscal incentives that may provide an attractive option. Non-fiscal incentives could include daytime access in urban areas which may otherwise be restricted.

Another area to focus is provision of dedicated parking spaces for EVs or more broadly ZEVs. It is suggested that an increasing proportion of parking spots in public spaces should be dedicated for cleaner vehicles.

Private companies should be encouraged to spend a part of their CSR funding on raising consumer awareness about cleaner vehicles in collaboration with academic and research institutes. This will include information on air quality, use of public transport, safety, and operational aspects of EVs, amongst others.

b) Policy Enablers

As mentioned previously, a National Clean Mobility Policy will provide certainty and clarity to all stakeholders and is therefore recommended. It should provide a broad vision including demand and supply side approaches along with proposed timelines. Such a policy should be evolved in broad consultation with industry, consumers, financial institutions, and other stakeholders. It should include proposals and preferred mechanisms for supporting demand incentives as well as non-fiscal incentives. Involvement and co-ordination of states is critical to ensure consistency and alignment of policies.

A related policy area is GST for ZEVs and components. A lower GST will encourage accelerated adoption and enable investments. Therefore, policy certainty on this matter is considered desirable and will signal ongoing support for e-mobility transition. It is further recommended to consider adopting uniform GST across the value chain to avoid liquidity crunch and litigation.

c) Enhancing Charging Infrastructure

Targeting the electrification of buses and trucks would require much greater ambition in rollout of public charging infrastructure. The upcoming FAME III may seek to allocate a larger proportion (say 20%-25%) of funds towards charging infrastructure, compared to FAME II, where 10% of the funds were earmarked for charging infrastructure. Allowing private investors to avail incentives under FAME III should be considered. Further, charging station operators should be encouraged to derive additional revenue streams, such as through extending benefits of gross/net metering, and creation of wayside amenities on highways.

The Parliamentary Standing Committee Report (2023) highlighted the importance of building up the charging infrastructure to ramp up EV penetration. Services such as battery swapping and charging at public charging stations attract GST rates of 18%. While corporates can avail input tax credit (ITC), consumers must absorb the same as a cost. Reducing GST on such services to 5% would benefit end consumers and boost adoption.

Interoperability in charging protocols must also be promoted in the short to medium term. This would allow users to recharge at any station and would hold relevance for heavy vehicles such as trucks, or buses. The government and industry will have to work together to devise open standards, ensuring interoperability. Such an initiative will be in line with India's strategy of promoting open standards and interoperability, as seen in the case of digital payments.

Granting the status of "social and commercial infrastructure" to charging infrastructure should be considered as it will enable a reduction in the cost of financing, as well as attract additional players.

It is also suggested that aggregation of charging infrastructure, combined with innovative business models maybe designed by states based on local context. Further, state regulatory commissions can design tariffs that incentivise optimal use of EVs, such as time of use or time of day tariffs (NRDC, 2023; CSE, 2023b) so that not only EVs benefit from lower operational cost but at the same time support the grid by using electricity during off peak hours.

It is also suggested that cities, particularly large ones with population exceeding 1 million, should develop charging infrastructure plan and encourage private participation through innovative business models.

d) Access to Finance

Designing financial instruments, particularly in heavy use cases such as buses and trucks will need to be considered. One option is to categorise EV loans under the "Priority Sector Loans" category in order to encourage banks to lend, who have traditionally been reluctant due to uncertainties emerging from lack of a secondary market.

To address the issue of secondary markets, industry players facilitated by one of the associations such as CII or SIAM should work towards establishment of a secondary market for EVs.

Establishing a secondary market will also require exploring alternative end of life (EoL) use cases for components such as batteries, especially those used in heavy vehicles, which may be used in energy storage applications. A working secondary market will enable EV financing at cheaper rates as both owners and financial institutions can be reasonably assured of deriving some value from used EVs.

Another option to consider is an interest subvention scheme for medium and heavy electric vehicles, particularly in urban settings, targeted towards small and medium fleet owners and operators given that they are generally constrained for funding. To keep it revenue neutral, such a scheme can also be designed and implemented through a feebate kind of system whereby additional revenue required is raised by implementing additional cess on traditional vehicles in the same segments.

Further, State Governments should work with RBI, State Finance Institutions, and banks to establish credit guarantee facility for e-mobility transition for heavier vehicles such as buses and trucks. Likewise, banks and NBFCs can be encouraged to develop leasing products and low-cost financing particularly for heavier vehicles, low- and middle-class customers etc.

A summary of proposed interventions along with key stakeholders is presented in Figure 5.11.

5.5.3 Supply Side Proposals (Medium to Long Term)

a) Policy Enablers

In the medium term, trade agreements to enable and enhance access to raw materials is a key area to focus on to develop the EV component ecosystem. For instance, the use of copper is likely to increase substantially for various applications, including EVs. The development of REE free motors will reduce dependence on PMSM but will require more copper. A long-term strategy will involve exploring and developing domestic sources, but also securing supplies in the international markets.

Trade agreements however need to be weighed considering domestic interest of building an industrial base and expanding employment in manufacturing. Similarly, localisation can also be accelerated by discouraging imports, particularly low quality or those subsidised to dump products or components. Quality control orders (QCOs) have been used in the past with the same intent. QCOs, devised in consultation with the industry, for components with large scope for localisation can be considered.

Another crucial material is electrical steel. It involves a complex manufacturing process and has a significant import dependency. In

Figure 5.11: Proposed Demand Side (Short to Medium term) interventions

Interventions	Government	Industry	Academic Institutions	Financial Institutions
Policy Initiatives				
Develop a National Clean Mobility Policy and Plan with a long-term perspective	MHI, NITI Aayog	Industry Associations	Various, Also Customer groups, thinktanks, NGOs	Various
Rationalize and provide long term stability for lower GST for EVs - Reduce eMobility Services (charging, battery swapping etc) to 5%.	MoF, GST Council			
Market Creation				
FAME III Scheme to continue demand incentives particularly for heavy vehicles	MHI, MoF			
Additional incentives through State E-Mobility policy	State Governments			
Extend tax benefit (Section 80 EEB) till 2030 or 50% penetration in 2W and 3W segment	MoF			
Non-fiscal incentives such as dedicated lanes, reserved parking for EVs	City administration, State Governments			
Propose targets for electrification of Buses	State Governments, MoHUA, MoEFCC	Large Companies	Schools, Colleges, Universities	
Consider ZEV mandates for cities with poor air quality	MoEFCC, CPCB			
Enhancing consumer awareness		OEMs, Industry Associations	Schools, Colleges, Universities	
Charging Infrastructure				
Allocate significant part of FAME III for Charging Infrastructure	MHI, NITI Aayog, MoF			
Encourage cities with population >1 million to develop Charging Infrastructure Plan	State Government, City Administrations			
Grant infrastructure status to public charging infrastructure under 'Social and Commercial Infrastructure'	MoF			RBI
Promote standardization and interoperability for charging stations and batteries	MoP | BEE	Industry Associations Charge Point Operators		
Encourage Industry led effort to develop secondary market for resale of EVs		OEMs, Industry Associations		
Access to Finance				
Include EV loans particularly buses, LCV and MHCVs in priority sector lending (PSL) norms.	MoF			RBI
Setup Green Transport Credit Risk Facility for risk mitigation in EV based public transport	State Governments			Banks, Large FIs
Encourage banks and finance companies to develop leasing products for EVs		OEMs, Industry Associations		Banks
Partner with NBFCs and banks to reduce cost of finance.		OEMs		Banks

Source: RTI Analysis

2023, India's electrical steel imports for various applications stood at USD 14 Billion, up from USD 8 Billion in 2020 with most imports originating from South Korea and China. In India, a few such as SAIL, JSW are producing, and others are considering investments. In the medium to long term, ramping up domestic capabilities in electric steel will be important.

To mitigate import dependence of REE magnets, neodymium will need to be mined domestically. Mining of neodymium will require technical and financial commitment from organisations such as IREL, particularly for processing and refining. Estimates by NITI Aayog and BCG (NITI Aayog & BCG, 2022) place this cumulative investment requirement in the tune of Rs. 10,000 to 13,000 Crores to meet the expected additional demand by 2030. These large investment requirements point to the need for exploring alternate sources of neodymium, such as through carbonatite reserves. According to the NITI and BCG study, less than 5% of India's mineral deposit reserves have been explored for carbonatite. Accelerating exploration of these alternative sources can inform the strategic direction taken in terms of motors. If mining is viable, cost effective and environmentally benign, it is possible to work towards reducing imports. However, if future R&D breakthroughs such as in ferrite magnets or in magnet-free motors are achieved, then large scale investments in exploration and mining may not be needed. Development of a technological roadmap for powertrain and power electronics, as recommended in the previous section will help informing the mining vs. R&D strategy for motors.

b) *Addressing Skill Gaps*

Building capabilities in various domains, particularly relating to motor design, power electronics, and battery chemistry etc. will be crucial to localisation of EVs. Many of these components will need indigenous designs considering the operating conditions in India. Building human resource capabilities with advanced knowledge in semiconductors will therefore be crucial.

Ezell (2024) noted that India has built up some capabilities in semiconductor design. With EVs driving greater synergies between the auto, the IT, and the electronics sectors, cross-industry and industry-academia collaboration can drive competitive advantage. EV and charging management software is an area of potential collaboration and similarly, the design capabilities being built up across industries can be leveraged for power electronics. Industry associations can take an active role to enable and accelerate this development by initiatives such as organising national and cluster level workshops to drive synergies.

It is assumed that specialised courses focused on EVs will be established. With increased penetration of EVs, more advanced courses focused on circularity, integration of AI, autonomous driving etc. will be needed to keep pace with developments.

Over the longer term, addressing the need for highly skilled manpower will require significant transformation of the education ecosystem, both at the school and university level. Such a transformation is envisaged in the New Education Policy 2020, but it is yet to be implemented in the spirit.

c) *Investing in R&D*

Technologies such as EVs and Artificial Intelligence and Machine Learning (AI-ML), IoT, and geospatial technologies, are likely to be increasingly integrated in the future. Leveraging India's competitive advantage in the software sector, inter-industry collaboration amongst electronics manufacturing, software development, and EV manufacturing can evolve as a competitive advantage for India in the future.

OEMs will benefit from vertical integration in the long-term and need to invest in R&D to strengthen capabilities. Developing capabilities in heavy vehicles such as trucks and buses can potentially provide avenues to also expand in adjacent sectors such as farm and construction equipment.

As EVs continue to be popularised across a range of use-cases, this presents a big opportunity to leverage the data generated to improve products on offer. Avenues such as driving pattern analysis and vehicle health analysis could be pursued. (KPMG, 2023).

Another area to focus on are electric motors. Given the import dependence on REEs for PM motors, and the high costs (both financial and environmental) of enabling mining of neodymium, one option is for the research agenda to focus on ferrite magnets which are REE free. Some companies such as Chara Technologies are already working in that direction. Alternatively, use of motors like induction, SRM, and synchronous motors can be explored.

Creation of grand challenges is suggested to provide a fillip to innovation in this space. Such competitive challenges can be designed to set out specifications such as size, robustness, torque, efficiency under operating conditions, amongst others. These specifications should be devised in consultation with the industry, academia, and startups.

While the existing centres of excellence should be leveraged to scale R&D efforts, the government may consider new and dedicated facilities focused on applied research. Such efforts can be undertaken in a hub and spoke model whereby new centres are created as umbrella institutions. A pertinent example of this approach is the 'Driving the Electric Revolution Industrialisation Centre' (DER-IC) in the UK. Created through a network of 30 institutions, the DER-IC offers the manufacturing value-chain support through access to specialists, open-access capital equipment, prototyping, testing, and training facilities. The UK government provided funding to set up the required facilities to institutions across the network. It is noted that the India Semiconductor Research Centre (ISRC) is expected to be operational soon, with funding support from the Government of India.

Similar models can be considered in other areas such as motor design, targeting the premier engineering institutions and universities of the country. The government can take support in terms of providing grants and finance to enable such centres, while the private sector can help design courses and degrees. These centres can be made self-sustaining by promoting commercialisation of research, aimed at solving problems for the industry. Core functions of such centres can be centred around the following: conducting R&D, mentoring startups, delivering skilling programmes, and providing simulation tools, testing and certification solutions (DST, 2024). Institutions around existing auto and auto component clusters can be considered.

e) Unlocking Access to Finance

Foraying into new technological areas requires risk capital, for which debt financing is unsuitable. Creating a dedicated venture capital or private equity fund for EV manufacturing, targeting startups and MSMEs can be considered by the government, financial institutions, and industry as a joint exercise (Micelio Mobility, NSRCEL, IIM Bangalore, and RMI India Foundation, 2022). Larger OEMs can contribute to the corpus, with the government providing a small portion of equity. This fund can offer a variety of financial instruments to startups and MSMEs, ranging from equity, venture debt, and grants, amongst others. The government and OEMs will have to continue to work together in building capabilities of Tier 1 and Tier 2 suppliers, focusing on quality control and process management. This will provide the foundation for enhanced and sustainable localisation as well as to capitalise on international market potential in the long-term.

f) GVC Enablers

As localisation levels increase, building and supporting EV clusters will be critical. Access to shared infrastructure, along with plug and play production enabling facilities can be provided by the government (NITI Aayog & ADB, 2022). These facilities can provide testing and prototyping infrastructure, ensuring availability of all tests available globally.

These EV clusters should leverage existing clusters and programs such as PM Gati Shakti to ensure optimal planning and access to infrastructure. State governments should take the lead in ensuring connectivity to larger national transport corridors. Other facilities that can be provided include social infrastructure such as housing, and health centres for employees.

It will also be critical to embed circularity in such upcoming clusters. Facilities for recycling wastewater, along with renewable power should be integrated. Creating shared recycling facilities to reuse and recycle EV components, and REE should be an integral part of such initiatives.

While electronic components have been used in the auto industry for some time, EVs are further accelerating this integration. Domestic manufacturing capabilities in this domain will hold increasing relevance for accelerating e-mobility transition. While efforts are underway towards localisation of semiconductors, scale is likely to be achieved in the medium to long-term. Ezell (2024) notes that the India Semiconductor Mission (ISM) extends generous incentives to attract semiconductor ATP and fabrication activity.

State governments will play an important role in the development of the industry. States such as Gujarat have taken the lead in providing land allocation, expedited approvals, and uninterrupted access to utilities such as power, water, and gas, combined with fiscal incentives. Similarly, Karnataka and Tamil Nadu provide capital subsidies and fiscal incentives to the EDSM industry. Since semiconductor design and fabrication requires large investments, policy continuity at central as well as at state level over the medium to long term will be critical for attracting investments. It is recommended that Joint Ventures with leading international firms may be adopted to provide easier access to technology, resources, capital, and international markets.

According to Ezell (2024), more than 150 chemicals, and over 30 gases and minerals are required across the semiconductor value chain. While domestic capabilities exist for many of these gases and chemicals, refinement capabilities will need to improve to meet the requirements of the semiconductor industry.

Ensuring adequate, high quality and reasonably priced supply of water and electricity are crucial for semiconductor manufacturing as it requires large quantities of both. Semiconductors require distilled water, or ultra-pure water (UPW), which has purity comparable to drinking or distilled water. With growth in chip manufacturing, the demand for UPW is likely to increase significantly (The Hindu, 2023) (Gradiant, 2022). For example, the TSMC fab in Arizona, USA will consume 8.9 Million gallons (33 Million litres) of water daily, with manufacturing of each chip requiring 8 gallons of water (around 30 L) Ezzel (2024).

While efforts to increase the mix of renewables in India's energy mix are already underway, circular economy principles should be at the core of the semiconductor industry, particularly when utilising scarce resources such as water. Further an efficient pricing regime will be needed to ensure optimum investment, supply and consumption of these resources,

5.5.4 Demand Side Proposals (Medium and Long Term)

Medium- and longer-term actions require to be decided and prioritised based on progress over the next few years. Hence, the precise form and timing of these actions is dependent on how the market and technology evolves and careful evaluation of the short-term actions already undertaken.

a) Market Creation and Demand Incentives

While demand-side fiscal incentives may need to continue into the medium term, a transition to non-fiscal incentives will be more sustainable in the longer term. Demand-side fiscal incentives should be gradually phased out as the industry scales and achieves competitiveness. Instead, demand generation through non-fiscal measures, combined with regulatory provisions such as purchase/sale obligations or targets may be more relevant.

It is suggested that the government takes a lead in this regard. Procurement of EVs or ZEVs is already proposed for government owned buses in the short-term action. In the medium to long term, all remaining traditional vehicles in government ownership maybe phased out. These could provide the scale necessary for local markets to justify investments and accelerate transition of private fleets.

Targets or purchase obligations should be discussed and introduced in collaboration with various stakeholders, particularly the industry. This will require building a consensus and a spirit of give and take on various related aspects. Mandates have been adopted in other sectors in India but require careful deliberations. Two recent and relevant examples of mandates are discussed briefly. First, in the transport sector, Delhi was mandated by the Supreme Court in 1998 to convert the entire commercial fleet to CNG which took a few years but enabled a complete transformation. Second, in case of renewable energy, mandates were introduced through legislative and regulatory route under the Electricity Act, 2003 mandating distribution utilities to procure a prespecified proportion of their power requirement from renewable sources. This process also took time but enabled new business models that helped in increasing penetration and driving the cost down. Overtime, the cost of solar energy has reduced to a level whereby the mandates are no longer required or relevant, as there is sufficient and growing market demand.

In the case of e-mobility, it is possible to stagger the targets or purchase obligations by first requiring large transport companies such as fleets used in moving cargo, waste, as well as goods delivered for e-commerce providers to electrify their fleets. Some of these maybe owned directly by public utilities such as municipal entities, while in other cases, the government can act as an enabler for the private sector to electrify their fleets. State governments will have to play an important role and take the lead in setting electrification targets. Feebate schemes can be designed to accelerate transition whereby government revenues are not stretched.

Alternatively, providing incentives to OEMs in the form of credit trading mechanisms can also be considered as a potential solution (CSE, 2023). OEMs can be allowed to earn green credits through the existing green credit programme, and trade them on the recently announced Indian Carbon Market (ICM).

Another option is to establish low-emission or zero-emission zones in cities, that freely allow EVs and other ZEVs, but traditional vehicles are either not allowed, or are required to pay a significant fee to enter these zones.

During medium to long term, a vibrant market for used EVs and used batteries should be prioritised to create a self-sustaining ecosystem. By repurposing batteries from electric vehicles for energy storage solutions or other use cases, it is possible to address two critical challenges. First, a thriving battery reuse market can significantly reduce the overall cost of EV ownership by extending the useable life of batteries beyond their primary application. Second, repurposed EV batteries can serve as valuable energy storage solutions, helping to integrate renewable energy sources like solar and wind into the grid more effectively.

Electrification of public transport fleets, via the GCC model is crucially dependent on payment security mechanisms. While guarantees can work in the short term, a longer-term solution is improving the financial health of STUs. Reform of these STUs should be a continued priority as it will need to be implemented over a period of time in phases, as evident from reforms in the power sector.

b) Charging Infrastructure

With roll-out of charging infrastructure expanding in cities, the focus must shift towards highways, sub-urban and rural areas under the target areas in the longer term. This is because the larger electrification opportunity for buses lies in private-operated, inter-city routes. Nearly 93% of all buses owned in India are in the private sector, and 80% of the market is in inter-city travel. While short distance routes with adequate charging infrastructure could achieve cost-parity in the medium term, however, challenges will remain in long distance routes.

A similar challenge exists in case of trucks, where power requirements for charging are at par with electric buses. In the long term, actions will consist of focusing on highways and expressways to ensure adequate charging stations. While charging could be dovetailed with scheduled stops, penetration of charging infrastructure beyond highways into sub-urban and rural areas will be crucial.

Charging management techniques and protocols will also need to be put in place to ensure effective demand management and efficiency in operations.

c) Finance

OEMs can work with financial institutions to introduce innovative business models such as leasing – wet and dry or short to long term leases which will reduce need for upfront capex and removing the risk of resale value. Flexible leasing models, providing both long-term and short-term leases can prove to be favourable particularly for smaller operators which dominate India's landscape. The airline industry is an example where different kind of leasing models already exist and have relevance for the bus industry, both in public and private sectors.

In the long run, particularly with the establishment of a secondary market and widespread availability of charging infrastructure, it is expected that the EV financing market will be self-sustaining and will operate on commercial considerations.

5.6 Summary and Conclusion

Sustainability and climate change are emerging as key considerations in industries with a large environmental footprint. Policy makers and consumers are demanding that products and processes change to enhance sustainability. E-mobility has emerged as a key response and is increasingly attractive because of technological evolution, lower cost in many segments and enhanced consumer experience.

This analysis revealed that the E-mobility transition is at the cusp of a take-off, with several segments demonstrating promising trends and technological maturity. India has taken decisive steps to enable and accelerate the transition. It is now poised to be among the leading markets. The transition itself is one of the largest economic opportunities for the country.

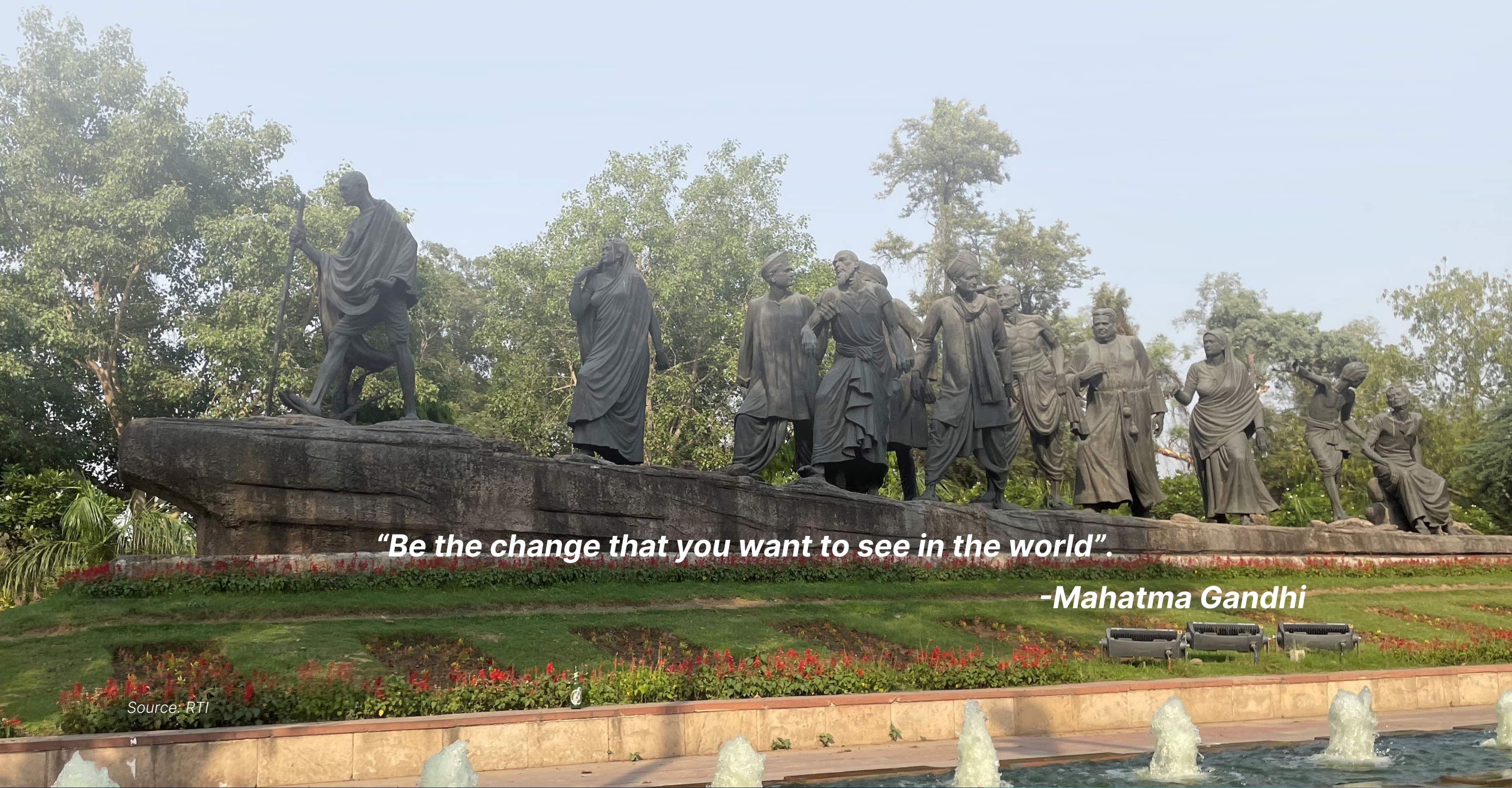
The automobile sector has demonstrated potential and needs to position itself to take advantage of the opportunity. Beyond the direct economic advantage, the e-mobility transition will enable improvement in urban air quality and reduce reliance on imported fossil fuels. Further, E-mobility will also support India's continued leadership to address the climate change challenge.

Realizing the opportunity will require large investment and sustained efforts. It is critical that the Government of India evolve a National Clean Mobility Policy in consultation with all stakeholders. This is perhaps one of the most important steps that the Government of India can take to mobilize and align the stakeholders around the vision. It will enable and accelerate investments, by industry and by individuals.

Private investments often follow the public sector. Central and state incentives for E-mobility have started a virtuous cycle, but the job is not over. Accelerating and expanding government incentives, particularly for public transport, heavier vehicles and charging infrastructure will be critical to enable the achievement of transformative scenario discussed in this report.

There is sufficient market interest for the private sector to invest with confidence. Expanded consumer choice through better products and innovative business models will accelerate the transition and enhance profitability across the industry. India's automobile industry has emerged as a global leader and this analysis suggests a strong uptick in the adoption of electric vehicles across the world. New players, technologies and business models will emerge as part of this transition. OEMs as well as the component suppliers will need to be nimble to adjust their strategies to incorporate emerging trends and develop innovative solutions.

Likewise, academia, think-tanks, and consumers need to invest their time and capital to support the transition. New skills and behaviours will be essential for sustainable growth and all stakeholders will need to adapt, modify their outlook and collaborate to enable the transition. As Mahatma Gandhi said, "be the change that you want to see in the world".



REFERENCES

- 6W Research, 2023. India Automotive Software Market (2024-2030) Outlook. s.l.:s.n.
- ABB, 2016. Driving Force. ABB Review.
- ACMA, 2021. EV Landscape - Opportunities for India's Auto component Industry, s.l.: s.n.
- ACMA, 2023. ACMA Press Conference - Indian Auto Component Industry Performace Review - FY 23.
- ACMA, 2023. Indian Auto Component Industry clocks highest-ever turnover of Rs. 5.6 lakh. s.l.:s.n.
- ACMA, 2023. Industry Statistics. s.l.:s.n.
- Advanced Propulsion Centre UK, 2022. Business Energy and Industrial Strategy Committee Inquiry: The semiconductor industry in the UK, s.l.: s.n.
- Advanced Propulsion Centre UK, 2023. Power electronics insight report, London: Advanced propulsion centre UK.
- AEMT, 2018. The Circular Economy And The Electric Motor Repair Industry, York, United Kingdom: The Association of Electrical and Mechanical Trades (AEMT).
- Al-Alawi, B. M. & Bradley, T. H., 2013. Review of Hybrid, Plug-In Hybrid, and Electric Vehicle Market Modeling Studies. Renewable and Sustainable Energy Reviews, Volume 21, pp. 190-203.
- Alternative Fuels Data Center (AFDC), 2024. Hydrogen Benefits and Considerations. [Online] Available at: https://afdc.energy.gov/fuels/hydrogen-benefits
- Aptiv, 2022. Annual Report 2022. s.l.:s.n.
- Arthur D. Little, 2023. GERMIX report, s.l.: s.n.
- Arthur D. Little, 2023. Transforming India into a Global Automotive Hub. s.l.:s.n.
- Ashok Leyland, 2023. Investor Presentation, s.l.: s.n.
- AutoCar, 2024. ZF produces its 1,000th CeTrax lite electric CV drive, demand from Isuzu grows. s.l.:s.n.
- Automotive World, 2023. EVR Motors signs fourth commercial agreement in India and establishes Indian manufacturing facility. s.l.:s.n.
- Avendus, 2020. The Economics of Electric Vehicles in India, s.l.: s.n.
- B Sudha, A. V. a. S. S., 2020. A review: high power density motors for electric vehicles. s.l., Journal of Physics: Conference Series.
- Bain & Company, 2022. Electric Vehicles are Poised to Create a $100B+ Opportunity in India by 2030, s.l.: s.n.
- Bain & Company, 2023. India Electric Vehicle Report 2023, s.l.: s.n.
- Bain, 2023. India Private Equity Report 2023, Mumbai: Bain & Company, Inc.
- BCG, 2023. How to Profit in Tomorrow's Automotive and Mobility Industry. s.l.:s.n.
- BCG, 2023. Rewriting the Rules of Software-Defined Vehicles. Boston: s.n.
- BEE, 2022. National Electric Mobility Mission Plan. s.l.:s.n.
- Blackberry, 2022. BlackBerry Expands Global Auto Software Business Into India With Mahindra. s.l.:s.n.
- Bloomberg, 2023. Indian Truckers Eye Electric as One Way to Tackle Pollution. [Online]
- Available at: https://www.bloomberg.com/news/articles/2023-07-20/indian-truckmakers-eye-electric-as-one-way-to-tackle-pollution
- Bloomberg, 2024. EVs Head for Junkyard as Mechanic Shortage Inflates Repair Costs. s.l.:s.n.
- Blume, 2023. Demystifying the Indian EV Ecosystem, s.l.: s.n.
- BMW Group, 2024. BMW Group and Tata Technologies aim to collaborate for the development of Automotive Software and Business IT solutions. s.l.:s.n.
- Bosch Mobility, n.d. [Online] Available at: https://www.bosch-mobility.com
- British Gas, n.d. Government EV charger grants to help you go green. [Online] Available at: https://www.britishgas.co.uk/smart-home/guides/electric-vehicles/EV-grants.html
- BSE, 2023. PERMANENT MAGNETS LIMITED - Presentation on Audited Financial Results for the quarter and year ended on March 31, 2023. s.l.:s.n.
- Business Line, 2023. Tractor industry clocks highest-ever domestic sales in FY23, s.l.: s.n.
- Business Standard, 2023. EV penetration: At 1.1%, India is far behind Asian average of 17.3%, New Delhi: s.n.
- Business Standard, 2024. Over 90% of fund gets used before FAME deadline; supports 1.5 mn vehicles. New Delhi: s.n.
- Business Today, 2022. How Indian Auto Suppliers are Dealing with the EV Conundrum, s.l.: s.n.
- Business Today, 2024. Tata Group's Dholera plant may roll out India's 1st semiconductor chip by 2026. s.l.:s.n.
- Capgemini, 2021. Next Destination: Software. s.l.:s.n.
- Casper, R. a. S. E., 2020. Electrification in the automotive industry: effects in remanufacturing. Journal of Remanufacturing, Issue 11, p. 121–136.
- CEEW, 2020. New Delhi: Council on Energy, Environment, and Water.
- CEEW, 2020. Financing India's Transition to Electric Vehicles, s.l.: s.n.

- CESL, 2022. Insight 2022: International Conference on Sustainable and Innovative Finance for Green and Healthy Transportation, s.l.: s.n.
- CESL, 2023. 'The Grand Challenge' for Electric Bus Deployment: Outcomes and Lessons for the Future, s.l.: s.n.
- Chara, 2023. Chara Technologies' Post. s.l.:s.n.
- CHARA, n.d. CHARA. [Online] Available at: https://www.chara.co.in/
- Cho, R., 2023. The Energy Transition Will Need More Rare Earth Elements. Can We Secure Them Sustainably?. [Online]
- CNBC, 2022. JSPL to invest Rs 7,930 crore under PLI scheme for specialty steel, says MD Bimlendra Jha. s.l.:s.n.
- Coffman, D. M., Bernstein, D. P. & Wee, S., 2015. Factors Affecting EV Adoption: A Literature Review and EV Forecast for Hawaii, s.l.: University of Central Florida.
- Commonwealth of Australia, 2021. Unlocking Australia-India Critical Minerals Partnership Potential, s.l.: Commonwealth of Australia.
- CORDIS, 2019. Designing and recycling electric motors. s.l.:s.n.
- Crisil, 2020. Getting charged: Two and three-wheelers to spearhead electric vehicle adoption, s.l.: s.n.
- CRISIL, 2022. EV share in auto components to be 9-11% by fiscal 2027: Shift presents both opportunities and challenges for auto component players. s.l.:s.n.
- Crisil, 2022. Subsidy Traction, s.l.: s.n.
- CRISIL, 2024. India Outlook 2024 Report. s.l.:s.n.
- Cyient, 2024. Cyient, First Indian Partner for Advanced Air Mobility with SkyDrive – Japan's Leading eVTOL Manufacturer. Hyderabad: s.n.
- Deloitte, 2020. 2020 Global Automotive Consumer Study. s.l.:s.n.
- Deloitte, 2021. Software Define Vehicles, forthcoming industrial revolution. s.l.:s.n.
- Deloitte, 2023. Software-defined vehicles: Engineering the mobility revolution. s.l.:s.n.
- Demeter, 2022. European Training Network for the Design and Recycling of Rare-Earth Permanent Magnet Motors and Generators in Hybrid and Full Electric Vehicles (DEMETER). [Online] Available at: https://etn-demeter.eu/
- Deolekar, O. & Tiwari, V., 2024. INVERTED DUTY STRUCTURE IN INDIA: ORIGIN, IMPACT AND SOLUTIONS, s.l.: ECGC.
- Donaldson, P., 2023. Motor Laminations. E-mobility Engineering.
- Drives & Controls, 2024. Project aims to offer a second life to motor components. [Online] Available at: https://drivesncontrols.com/news/fullstory.php/aid/7551/Project_aims_to_offer_a_second_life_to_motor_components.html
- DST, 2024. White paper on Evolution Catalysing Technology led Ecosystem for E mobility, New Delhi: DST.
- Economic Times, 2022. Attero expects 65 pc of USD 2 billion revenue target in 5 years to come from Lithium-ion recycling. s.l.:s.n.
- Economic Times, 2022. India's shift to electric vehicles will lead to more copper imports. s.l.:s.n.
- Economic Times, 2023. Deeptech startup Chara raises $4.75 million from Exfinity, others. s.l.:s.n.
- Economic Times, 2023. Global capability centers follow top tech talent to India's heartland. s.l.:s.n.
- Economic Times, 2023. Govt charts plan to paint 800k diesel buses green, scheme likely to replace FAME III. s.l.:s.n.
- Economic Times, 2023. India is Becoming Key to Automakers. s.l.:s.n.
- Economic Times, 2023. Strong private consumption major driving force of India's eco growth: Fin Min Eco Review. s.l.:s.n.
- Economic Times, 2024. Ford set to build more EV software abilities in Chennai. s.l.:s.n.
- Economic Times, 2024. Govt forms panel to examine demands for inclusion of more components in Auto PLI: Minister. s.l.:s.n.
- Economic Times, 2024. Sona Comstar gets certification under auto PLI scheme. s.l.:s.n.
- Economic Times, 2024. Tata, Mahindra, and Ola eye double benefit of Auto PLI and FAME with early approvals. s.l.:s.n.
- Edmondson, D. J., 2022. Electric Motors for Electric Vehicles 2022-2032, s.l.: IDTechEx.
- EE Power, 2023. Securing the Supply of Electrical Steel in EV Motors. s.l.:s.n.
- EE Power, 2024. Reclaiming Rare Metals by Repurposing Used EV Motors. s.l.:s.n.
- EIB, 2023. Circular Economy Overview 2023. p. 8.
- Electric Motor Engineering, 2023. The rare-earth-free Indian electric motor. s.l.:s.n.
- Electrive, 2018. https://www.electrive.com/2018/02/20/toyota-develops-magnet-rare-earth-metals/. s.l.:s.n.
- Electrive, 2022. How the semiconductor crisis really affects electric cars. s.l.:s.n.
- Energy Monitor, 2023. Signal: India's plan for 50,000 electric buses gets US support, s.l.: s.n.
- Ernst & Young, 2021. Production-linked incentive schemes in India: The journey so far. s.l.:s.n.
- ET Auto, 2023. Fame III for electric vehicles: Govt plans up to INR 50,000 crore outlay. s.l.:s.n.
- ET Energyworld, 2023. EV maker Lohia Auto to launch high speed scooters, new three-wheeler. The Ecionomic Times - Energyworld, 9 November.
- ET Telecom, 2023. India set to approve Micron's $3b chip packaging & test unit. s.l.:s.n.
- European Commission, 2019. EU-funded project DEMETER develops the first recycled electric motor. s.l.:s.n.

- European Parliament, 2022. Deal confirms zero-emissions target for new cars and vans in 2035. s.l.:s.n.
- EV reporter, 2022. Electrical steel prices a big worry for EV component makers in India [Online] Available at: https://evreporter.com/electrical-steel-prices-a-big-worry-for-ev-component-makers-in-india/
- EV Reporter, 2022. Rare-earth free motors for electric vehicles | Chara Technologies. s.l.:s.n.
- EV Tech News, 2023. EVR Motors' new developments for multiple mobility applications. s.l.:s.n.
- EVR Motors, 2024. Israel's EVR motors plants India manufacturing footprint. s.l.:s.n.
- EY, 2022. Electrifying Indian Mobility, s.l.: s.n.
- EY, 2023. From Blueprint to Global Dominance: The expected evolution of India's electronics manufacturing services sector. s.l.:s.n.
- EY, n.d. The software-driven revolution redefining the automotive industry. s.l.:s.n.
- Ezell, S., 2024. Assessing India's Readiness to Assume a Greater Role in Global Semiconductor Value Chains, Washington D.C.: Information Technology and Innovation Foundation.
- FICCI, 2019. Sector Insight: Indian Automobile Sector Slowdown, s.l.: s.n.
- FICCI, 2023. New Age Energy Minerals, Delhi: FICCI.
- Financial Express, 2024. Omega Seiki partners Attero for EV battery reuse lifecycle management, targets to recycle 100 MWh of battery in 4 years. s.l.:s.n.
- Fortune Business Insights, 2022. India Electric Vehicle Market Size, Share, & Covid-19 Impact Analysis, by Platform and Regional Forecasts, 2022-2029, s.l.: Fortune Business Insights.
- Friedrichs, P., 2023. Comparison of EV motors, the EV sector's demand of commodities and the Chinese market influence - A brief review.
- Frost and Sullivan, 2022. The transition of Electric Mobility from 400V to 800V Architecture – An Inevitable move towards WBG semiconductors. Power Electronics News.
- FTP, 2024. FPT Automotive Opens India Office, Expanding Automotive Software Market. s.l.:s.n.
- Gauß, R. et al., 2021. Rare Earth Magnets and Motors: A European Call for Action, Berlin: European Raw Materials Alliance.
- German Design Award, 2024. Tata Motors Gen 3 HMI Design. s.l.:s.n.
- GKN Automotive, 2022. GKN Automotive to collaborate in SCREAM project to develop circular supply chain for recycled rare-earth magnets. s.l.:s.n.
- Globe Newswire, 2022. Mkango and HyProMag to Collaborate in Major New Grant-Funded Project to Recycle Rare Earth Magnets From Electronic Waste, Electric Motors and Wind Turbines for the UK Supply Chain. s.l.:s.n.
- Government of India, 2022. Lok Sabha Secretariat. [Online]
- Available at: https://loksabhadocs.nic.in/Refinput/New_Reference_Notes/English/15072022_175056_1021205203.pdf
- Gradiant, 2022. India's chip plans to stimulate UPW market | Global Water Intelligence. Gradiant.
- Grant Thornton, 2023. Auto-Electronics Manufacturing: Conquering the Next Frontier. s.l.:s.n.
- H2 Green Steel, 2023. ZF relies on green steel. s.l.:s.n.
- Hadraoui, H. E. et al., 2022. A Multi-Criteria Analysis and Trends of Electric Motors for Electric Vehicles. World Electr. Veh. J..
- HashList, 2023. Automotive Tech Hubs in India. s.l.:s.n.
- HCL, 2023. HCLTech to acquire German automotive engineering services company ASAP Group. s.l.:s.n.
- HCL, 2024. Work from Car (WFC) and Bank in Car (BIC) are the automotive trends here to stay. s.l.:s.n.
- Hemsen, J., Nowak, N. & Eckstein, L., 2023. Production cost modeling for permanent magnet synchronous machines for electric vehicles. Automotive and Engine Technology.
- HillmanCurtis, 2022. The Rapid Growth and Prospects of the India PCB Industry. s.l.:s.n.
- Hindustan Copper Limited (HCL), 2023. Annual Report 2022-23, Kolkata: HCL.
- ICA & IESA, 2023. Evaluating the Electric Vehicle Supply Chain and Scope of Indigenization, s.l.: s.n.
- ICAI, 2024. Copper Demand in India - Annual Study FY 2023. s.l.:s.n.
- ICEA, 2022. $300 BN SUSTAINABLE ELECTRONICS MANUFACTURING & EXPORTS BY 2026, s.l.: s.n.
- ICRA, 2023. Indian Automotive Industry, s.l.: s.n.
- IDTechEx, 2024. Removing Rare-Earths Drives Demand for Copper in EV Motors. [Online] Available at: https://www.idtechex.com/en/research-article/removing-rare-earths-drives-demand-for-copper-in-ev-motors/30428
- IEA, 2022. Global EV Outlook 2022, s.l.: s.n.
- IEA, 2023. Transitioning India's road transport sector, s.l.: s.n.
- IEA, 2024. Global EV Outlook 2024. s.l.:s.n.
- IMF, 2023. World Economic Outlook Database. s.l.:s.n.
- Inc 24, 2023. How Attero Clocked INR 300 Cr In Revenue By Recycling E-Waste Into Industrial Gold. s.l.:s.n.
- India Briefing, 2024. India's New EV Policy Seeks to Attract Investments from Leading Firms like Tesla. s.l.:s.n.
- Indian Express, 2024. India to leverage US-led Minerals Security Partnership to help PSUs secure critical mineral assets abroad. Indian Express.
- International Copper Association (ICA), 2020. Copper Demand in Electric Traction Motors 2020 - 2030. s.l.:s.n.
- International Energy Agency, 2023. Dual Credit System. [Online] Available at: https://www.iea.org/policies/14779-dual-credit-system
- Inventiva, 2023. Top 20 Automotive Softwares in India 2023. s.l.:s.n.

- Invest India, 2022. National Logistics Policy in India. s.l.:s.n.
- Invest India, 2023. Green Aviation: India's Path to Net Zero Carbon Emissions by 2050. s.l.:s.n.
- Invest India, 2024. Invest India: Sector Automobile. [Online] Available at: https://www.investindia.gov.in/sector/automobile
- Islamovic, M. & Lind, T., 2021. Development of a new forecasting equation simulating EV sales globally: A combination approach, s.l.: s.n.
- Jina, H. et al., 2016. Comparative Life Cycle Assessment of NdFeB Magnets: Virgin Production. 23rd CIRP Conference on Life Cycle Engineering.
- JMK Research and Analytics, 2022. Electric 2W market in India, s.l.: s.n.
- Kalaari Capital, 2021. Why We Invested in Chara. s.l.:s.n.
- Keil, 2018. In-vehicle Infotainment - The Automotive Cockpit of the Future. s.l.:s.n.
- KPIT, 2022. KPIT and Technica Engineering join forces to accelerate the transformation towards. s.l.:s.n.
- KPIT, 2022. Renault Group selects KPIT as a strategic technology partner for next generation Software-Defined Vehicle(SDV) program. s.l.:s.n.
- KPMG, 2023. Technology at the forefront of electric vehicles, s.l.: s.n.
- L&T TS, 2023. Beyond the Billion: Annual Report 2022-23. s.l.:s.n.
- Live Mint, 2022. Attero eyes 65% of $2 bn revenue in 5 yrs to come from lithium-ion recycling. s.l.:s.n.
- Live Mint, 2022. Attero to expand recycling capacity, plans IPO in 2025. s.l.:s.n.
- Live Mint, 2024. Govt wants to certify all automotive PLI applicants by July. s.l.:s.n.
- Lok Sabha, 2022. Reference Note: National Clean Air programme. Delhi: PARLIAMENT LIBRARY AND REFERENCE, RESEARCH, DOCUMENTATION AND INFORMATION SERVICE (LARRDIS).
- Madichetty, S., Neroth, A. J., Mishra, S. & Babu, B. C., 2022. Route Towards Road Freight Electrification in India: Examining Battery Electric Truck Powertrain and Energy Consumption, s.l.: s.n.
- Magna, 2022. Magna Expands Presence in India, Invests in New Engineering Center. s.l.:s.n.
- Marelli, 2022. Marelli expands innovation capabilities with a new Technical R&D center in Bangalore. s.l.:s.n.
- Massimiliano Gobbi, A. S. R. P. G. M., 2023. Traction motors for electric vehicles: Maximization of mechanical efficiency - A review. Applied Energy, 357(March 2024).
- McKinsey & Company, 2017. Hydrogen: The next wave for electric vehicles?, s.l.: s.n.
- McKinsey & Company, 2018. The auto component industry in India: Preparing for the future. s.l.:s.n.
- McKinsey & Company, 2019. In India 17% cars would be sold to fleet owners and taxi operators by 2025: McKinsey. ET Auto.
- McKinsey & Company, 2020. The unexpected trip: The future of mobility in India beyond COVID-19, s.l.: s.n.
- McKinsey & Company, 2023. Automotive software and electronics 2030: Mapping the sector's future landscape. s.l.:s.n.
- McKinsey & Company, 2023. Autonomous driving's future: Convenient and connected. s.l.:s.n.
- McKinsey & Company, 2023. Battery recycling takes the driver's seat. s.l.:s.n.
- McKinsey & Company, 2023. Consumers are driving the transition to electric cars in India, s.l.: s.n.
- MCX, 2024. Copper Performance REview. [Online] Available at: https://www.mcxindia.com/docs/default-source/products/metals/performance-review/mcx_copper_performance-review-22-23.pdf?sfvrsn=15f5aa91_2
- MeitY, 2023. The Digital Personal Data Protection Act, 2023 (No. 22 of 2023). New Delhi: Ministry of Law and Justice, Government of India.
- MHI, 2024. MHI Notification. [Online].
- Micelio Mobility, NSRCEL, IIM Bangalore, and RMI India Foundation, 2022. Catalysing E-Mobility, s.l.: s.n.
- Ministry of Commerce, 2023. Export Import Data Bank, s.l.: s.n.
- Ministry of Commerce, 2024. Trade Satistics. [Online] Available at: https://tradestat.commerce.gov.in/meidb/brcq.asp?ie=e
- Ministry of Mines, 2024. Copper. [Online] Available at: https://mines.gov.in/webportal/copper
- Ministry of Science & Technology, 2022. Improved, heavy rare earth-free, low-cost magnets for EV vehicles could reduce mobility costs.
- MNRE, 2023. National Green Hydrogen Mission. s.l.:s.n.
- MNRE, 2023. R&D Roadmap for Green Hydrogen in India, s.l.: s.n.
- MNRE, 2024. Scheme Guidelines for implementation of Pilot projects for use of Green Hydrogen in the Shipping Sector under the National Green Hydrogen Mission (NGHM). New Delhi: s.n.
- MoHUA, 2023. Guidelines for PM e-Bus Sewa. s.l.:Ministry of Urban Development and Housing.
- MoPGN, n.d. PNGRB (upcoming projects & key regulations). s.l.:s.n.
- MoP, n.d. Electric Vehicle: Regulations and Guidelines Issued by Ministry of Power. s.l.:s.n.
- MoPNG, 2021. Draft LNG Policy: Strategies to increase LNG usage as Transport Fuel and in Mining Sector. New Delhi: s.n.
- MoPNG, n.d. City Gas Distribution. s.l.:s.n.
- Mordor intelligence, 2023. India connected car market size.
- MoRTH, 2023b. Basic Road Statistics of India 2020. s.l.:Ministry of Road Transport & Highways.
- Nebel, C. E., 2023. CVD diamond: a review on options and reality. *Functional Diamond*, 3(1).
- Nippon Steel, 2019. Non-oriented Electrical Steel Sheet and Its Application Technology for the Traction Motors of Hybrid/Electrical Vehicles.

- NITI Aayog & ADB, 2022. Driving affordable financing for electric vehicles in India. s.l.:s.n.
- NITI Aayog & BCG, 2022. Promoting Clean Energy Usage Through Accelerated Localization of E-Mobility Value Chain. s.l.:s.n.
- NITI Aayog & RMI, 2019. India's Electric Mobility Transformation. s.l.:s.n.
- NITI Aayog & RMI, 2022. Transforming Trucking in India: Pathways to Zero-Emission Truck Deployment, s.l.: s.n.
- NITI Aayog and Green Growth Equity Fund Technical Cooperation Facility, 2022. Advanced Chemistry Cell Battery Reuse and Recycling Market in India. s.l.:s.n.
- NITI Aayog, RMI, 2022. Transforming Trucking in India: Pathways to Zero-Emission Truck Deployment, s.l.: s.n.
- NITI Aayog, 2020. A Roadmap for Creating Global Champions in Automotive Industry in India. s.l.:s.n.
- NITI Aayog, 2021. Roadmap for Ethanol Blending in India 2020-25 Report of the Expert Committee. s.l.:s.n.
- NITI Aayog, 2022. ZEVTC Declaration. [Online] Available at: https://e-amrit.niti.gov.in/zevtc-declaration
- Nomura Research Institute Consulting & Solutions India Pvt. Ltd. (NRI), 2021. Holistic Assessment of Alternate Powertrains for Passenger Vehicles in India, Gurgaon: Nomura Research Institute Consulting & Solutions India Pvt. Ltd.
- NRDC & ASCI, 2023. ENERGIZING FREIGHT: Policy Toolkit for Medium and Heavy-Duty Truck Electrification in India. s.l.:s.n.
- OICA, 2022. Production Statistics. [Online] Available at: https://www.oica.net/category/production-statistics/2022-statistics/
- OLA, 2022. Ola Announces Futurefoundry. s.l.:s.n.
- Oliver Wyman, 2018. FAST 2030: Oliver Wyman study on the Future Automotive Industry Structure. s.l.:s.n.
- Ostara Advisors, 2024. The Ostara Review: The Indian EV ecosystem in 2023. [Online] Available at: https://ostaraadvisors.substack.com/p/the-ostara-review-the-indian-ev-ecosystem
- P&S Intelligence, 2020. Indian Electric Vehicle Component Market Research Report: Two-Wheeler (Scooters, Motorcycle), Three-Wheeler (E-Rickshaw, E-Auto, Retrofitted Rickshaw), Passenger Car, Commercial Vehicle – Industry Analysis and Growth Forecast to 2030. s.l.:s.n.
- Parliamentary Standing Committee, 2023. 324th Report on Promotion of Electric Vehicles in the Country (Presented to Rajya Sabha). s.l.:s.n.
- Perforce, n.d. [Online] Available at: https://www.perforce.com/blog/vcs/automotive-software
- Permanent Magnets Limited, 2023. Trust Reliability Quality: Investor Presentation Q4 FY23, s.l.: s.n.
- PIB, 2019. FAME India Scheme. s.l.:s.n.
- PIB, 2019. Year Ender 2019 Ministry of Heavy Industry. s.l.:Ministry of Heavy Industries & Public Enterprises.
- PIB, 2022. Cabinet approves modifications in "Programme for Development of Semiconductors and Display Manufacturing Ecosystem in India". Delhi: s.n.
- PIB, 2022. Government of India to expand Public Electric Vehicle Charging Infrastructure across the nation. Delhi: s.n.
- PIB, 2022. Improved, heavy rare earth-free, low-cost magnets for EV vehicles could reduce mobility costs. s.l., s.n.
- PIB, 2022. India Semiconductor Mission. Delhi: s.n.
- PIB, 2022. Make in India. Delhi: s.n.
- PIB, 2022. MHA and SECI sign MoU to realize India's green energy initiative. s.l.:s.n.
- PIB, 2022. Ministry of Heavy Industries sanctions 1576 EV Charging Stations across 16 Highways & 9 Expressways under Phase-II of FAME India Scheme. Delhi: s.n.
- PIB, 2022. National Rail Plan aims to increase share of freight traffic from current percentage of 27 to 45 by 2030. Delhi: s.n.
- PIB, 2023. 66 Indian Airports are operating on 100% Green Energy. Delhi: s.n.
- PIB, 2023. Decarbonization of transport sector essential to reduce GHG emissions, achieve net-zero emissions by 2070. Delhi: s.n.
- PIB, 2023. Government invites applications for setting up Semiconductor and Display Fabs as per Modified Semicon India Programme from 1st June.
- PIB, 2023. India aims at becoming 'Global Hub for Green Ship' building by 2030 with launch of Green Tug Transition Programme(GTTP).
- PIB, 2023. India has been selected as pioneer lead country for International Maritime Organization (IMO) Green Voyage 2050 Project. Delhi: s.n.
- PIB, 2023. Indian Railways to become Net Zero Carbon Emitter by 2030. Delhi: s.n.
- PIB, 2023. India's Soaring Skies: Booming Aviation Sector.
- PIB, 2023. Industry Leaders Forge Alliance for increasing Demand of Electric Freight Vehicles, s.l.: s.n.
- PIB, 2023. Initiatives taken by MoCA to promote sustainable development in the aviation sector and reduce carbon emissions at airports. Delhi: s.n.
- PIB, 2023. Milestone in India and Australia reach Critical Minerals Investment Partnership. s.l., s.n.
- PIB, 2023. Mining of Rare Earth Elements. s.l., s.n.
- PIB, 2023. National Clean Air Programme (NCAP) to improve air quality in 131 cities by engaging all stakeholders. Delhi: s.n.
- PIB, 2023. Net zero emissions target. Delhi: s.n.
- PIB, 2023. NITI Ayog convenes India's Electric Mobility Enablers under G20 Presidency. s.l.:s.n.
- PIB, 2023. PLI Schemes contribute to increase in production, employment generation, and economic growth. s.l., s.n.
- PIB, 2023. PM e-Bus Seva Scheme. Delhi: s.n.
- PIB, 2023. Salient Features of the Digital Personal Data Protection Bill, 2023. Delhi: s.n.

- PIB, 2023. STRENGTHENING OF MINERAL SUPPLY CHAINS. s.l., s.n.
- PIB, 2023. The Automobile Sector in India. s.l.:s.n.
- PIB, 2023. Thirty Critical Minerals List Released. s.l., s.n.
- PIB, 2024. Deendayal Port, Paradip Port and V.O. Chidambaranar (Tuticorin) Port to be developed as Green Hydrogen hubs: Union Power and New & Renewable Energy Minister. Delhi: s.n.
- PIB, 2024. Government approves E-Vehicle policy to Promote India as a Manufacturing Destination for e-vehicles. Delhi: s.n.
- PIB, 2024. Government issues Guidelines for Pilot Projects for utilizing Green Hydrogen in Shipping Sector. Delhi: s.n.
- PIB, 2024. Launch of Exploration Licence for Critical and Deep Seated Minerals by the States of Karnataka and Rajasthan - A First in the Country.
- PIB, 2024. Ministry of Heavy Industries announces Electric Mobility Promotion Scheme 2024. Delhi: s.n.
- PIB, 2024. PLI for Auto Gains Momentum; Successful in attracting proposed investment of ₹ 67,690 crore against the target estimate of investment ₹ 42,500 crore over a period of five years. Delhi: s.n.
- PIB, 2024. Scheme outlay of FAME India Scheme Phase II enhanced from ₹10,000 crore to ₹11,500 crore. s.l., s.n.
- PM Review, 2022. SCREAM project to establish recycled rare earth source for sintered magnets in UK. s.l.:s.n.
- PM Review, 2024. REASSERT project to develop strategies for remanufacturing and recycling electric motors. s.l.:s.n.
- PNGRB, 2008. Notified Regulation: Exclusivity for city or local natural gas distribution network. s.l.:s.n.
- PPAC, 2023. Ready Reckoner FY 2022-23 - Snapshot of India's Oil & Gas data, s.l.: https://ppac.gov.in/uploads/rep_studies/1681883210_Snapshot_of_India_Oil_Gas_data_Mar_2023_upload.pdf.
- PIB, 2024. Soon India will be the 3rd largest economy in the world.
- Product-Life Institute, n.d. CNG Delhi – the world's cleanest public bus system running on CNG. s.l.:s.n.
- PV Magazine, 2022. Attero to invest $72.4 million in setting up 'world's most advanced' Li-ion battery recycling plant in Telangana. s.l.:s.n.
- PwC, 2022. Electric Vehicles and e-Mobility, s.l.: s.n.
- PwC, 2022. Winning the EV race through localisation: An India perspective, s.l.: s.n.
- Rajya Sabha Secretariat, 2023. 324th Report on Promotion of Electric Vehicles in the Country. New Delhi: s.n.
- Rassõlkina, A. et al., 2020. Life cycle analysis of electrical motor¬drive system based on electrical machine type. Proceedings of the Estonian Academy of Sciences, 69(2), p. 162–177.
- Research & Markets, 2023. India Automotive Software Market (2023-2028). s.l.:s.n.
- Reuters, 2018. New Toyota magnet cuts dependence on key rare earth metal for EV motors. s.l.:s.n.
- Reuters, 2021. Automakers cutting back on rare earth magnets. [Online] Available at: https://www.reuters.com/business/autos-transportation/automakers-cutting-back-rare-earth-magnets-2021-07-19/
- Reuters, 2023. The automakers and suppliers pushing to cut rare earths from EVs. [Online]
- Available at: https://www.reuters.com/business/autos-transportation/automakers-suppliers-pushing-cut-rare-earths-evs-2023-11-14/
- Reuters, 2024. India aims for green shipping on inland waterways in five years - officials. New Delhi: s.n.
- Reuters, 2024. India trade department backs lower tax on hybrid cars in green push- sources. Reuters, January.
- Ricardo, 2023. Developing Trends & Challenges for SiC Based Power Inverters. [Online] Available at: https://www.ricardo.com/en/news-and-insights/insights/developing-trends-challenges-for-sic-based-power-inverters
- RMI & NITI Aayog, 2022. Transforming Trucking in India, s.l.: s.n.
- RMI, 2023. X-change: Cars, The end of the ICE age, s.l.: s.n.
- Roush Industries Inc, 2022. Technical Review of Medium and Heavy-Duty Electrification for MY 2027-2030, s.l.: EDF.
- S&P, 2021. Electrical steel – Another temporary supply chain shortage or a threat to OEMs' electrification plans?.
- SAE, 2014; Revised 2021. SAE Levels of Driving Automation. s.l.:s.n.
- Schaeffler, 2024. REASSERT project: A second life for electric motors. Bühl: s.n.
- SCREAM, 2023. SECURING CRITICAL RARE EARTH MAGNETS FOR THE UK SUPPLY CHAIN. [Online] Available at: https://scream-uk.com/#
- Shimin V.V, V. S. M. M. L., 2016. Advanced Material Selection for Semiconductor Switching Devices in Electric Vehicles Using PROMETHEE Method. s.l.:s.n.
- Shravan, R., 2023. Roadmap to Innovation: How electric trucks can transform the trucking industry in India. Times of India, August.
- SIAM, n.d. Pre-Budget Memorandum. s.l.:s.n.
- Singh, C. a. J., 2020. Financing India's Transition to Electric Vehicles. Council for Energy, Environment and Water: Centre for Energy Finance. s.l.:s.n.
- SMEV, 2023. Recommendations by Society of Manufacturers of Electric Vehicles (SMEV) for Union Budget 2023-24. s.l.:s.n.
- Southern Railways, 2021. Hydrogen Fuel Cell-based Train on Indian Railway Network. Chennai: s.n.
- Statista, n.d. Number of public and private sector buses across India from financial year 2001 to 2020. [Online] Available at: https://www.statista.com/statistics/667422/buses-in-the-public-and-private-sector-india/#statisticContainer

- Stellantis, 2022. Stellantis Further Expands Software Hub: Inaugurates New, State-of-the-Art Software and Technology Center in Bengaluru, India. Mumbai, Amsterdam: s.n.
- Synetiq, n.d. How SYNETIQ support electric vehicle circularity. [Online] vailable at: https://www.synetiq.co.uk/electric-and-hybrid-solutions/
- Tata Elxsi, 2017. Tata Elxsi wins the coveted international iF Design Award 2017 for design. Bangalore: s.n.
- Tata Elxsi, 2023. Tata Elxsi wins three e4M India Design Excellence Awards. s.l.:s.n.
- Tata Steel, 2023. Growth with Purpose - Integrated Report and Annual Accounts 2022-23. s.l.:s.n.
- Tech Mahindra, 2023. Tech Mahindra and Anyverse partner to accelerate AI Adoption in the Automotive Industry. Bangalore: s.n.
- TechSci Research, n.d. Industrial Technology Trend Survey - AI, Robotics, Quantum Technology, Semiconductor and Space. [Online]
- Available at: https://www.nedonewdelhi.in/assest/pdf/Techsiwebsiterev.pdf
- Thales, 2023. A single automotive cyber security standard at last: WP.29. s.l.:s.n.
- The Climate Group, 2022. Early Market Outlook Report - Electrification of medium and heavy-duty trucks in India, s.l.: s.n.
- The Economic Times, 2024. First chip from Tata's Dholera plant will be out in December 2026: Ashwini Vaishnaw. [Online]
- Available at: https://economictimes.indiatimes.com/industry/cons-products/electronics/first-chip-from-tatas-dholera-plant-will-be-out-in-december-2026-ashwini-vaishnaw/articleshow/108460607.cms?from=mdr
- The Hindu, 2023. India in line to emerge as potential global leader in battery-swapping tech. Hindu Business Line, The Hindu.
- The Hindu, 2023. Lacking resources. India lacks talent for chip manufacturing; requires 10-13k resources by 2027: Meity official. The Hindu Business Line.
- The Hindu, 2023. Semiconductor industry to fuel demand for ultrapure water: Thermax. The Hindu.
- The Global Economy, 2024. Country rankings: Passenger car & Commercial vehicle sales.
- TIFAC & NITI Aayog, 2022. Forecasting penetration of electric two-wheelers in India, s.l.: s.n.
- TIFAC, 2018. R&D Plan for Technology Platform on Electric Mobility (NMEB). s.l.:s.n.
- Tiwari, D. M. J., Tiwari, A. & and Jewell, G. W., 2021. A Review of Circular Economy Research for Electric Motors and the Role of Industry 4.0 Technologies. The Special Issue of Distributed and Sustainable Manufacturing, 2021, 09 July, p. 19.
- ToI, 2018. India needs 30 lakh buses for transport, has only 3 lakh. [Online]
- Available at: https://timesofindia.indiatimes.com/india/india-needs-30-lakh-buses-for-transport-has-only-3-lakh/articleshow/65726517.cms
- Toyota, 2023. Toyota unveils new technology that will change the future of cars. s.l.:s.n.
- Tracxn, 2024. Tracxn Database. s.l.:s.n.
- Traxcn, 2024. Summary of Funding Rounds of Attero. s.l.:s.n.
- TulaTech, 2022. White paper: Rare Earth Materials and their Impact on the Future of Electric Motors. s.l.:s.n.
- TUMI, 2023. Development of the India Zero Emission Bus Market: Investor's Guide. s.l.:s.n.
- UITP, 2022. Performance Evaluation of Electric Bus from Six Indian Citieds. s.l.:UITP (Union Internationale des Transports Publics).
- UNECE, n.d. WP.29 - Introduction. s.l.:s.n.
- UNIDO, 2023. Indian Automotive Sectorial System Of Innovation (IASSI). University of Birmingham, 2023. First production of recycled magnets at Tyseley Energy Park, Birmingham. s.l.:s.n.
- Upadhayay, P., Lebouc, A.-K. & Garbuio, L., 2018. Applicability of Direct Reuse and Recycled Rare Earth Magnets in Electro-mobility. 7th International Conference on Renewable Energy Research and Applications (ICRERA 2018), p. 8.
- USAID-SAREP, n.d. E-Mobility. [Online] Available at: https://sarepenergy.net/event_sectors/emobility/
- USITC, 2019. Building Vehicle Autonomy: Sensors, Semiconductors, Software and U.S. Competitiveness. s.l.:s.n.
- VAHAN Dashboard, 2023. s.l.:s.n.
- Valeo, 2024. High Voltage Rare Earth Free Electric Motor. s.l.:s.n.
- Vasileios Rizos, E. R. A. K., 2022. Developing a Supply Chain For Recycled Rare Earth Permanent Magnets in the EU, s.l.: s.n.
- Volvo, 2022. Volvo Group expands its R&D operations in India to become the largest site outside Sweden. s.l.:s.n.
- W.Thamke, P., Yewale, N. M., Vaidya, U. B. & G., P., 2015. Faults Associated With Permanent Magnet Synchronous. International Journal Of Core Engineering & Management (IJCEM), 2(3), p. 7.
- Wipro, 2024. General Motors, Magna, and Wipro Team Up to Develop Automotive Software Marketplace: 'SDVerse'. Detroit: s.n.
- Wired, 2023. The Real Reason EV Repairs Are So Expensive. s.l.:s.n.
- World Bank, 2022. Electric Mobility Market Assessment, Business Model and Action Plan in India, s.l.: s.n.
- WorldBank, 2022. Final consumption expenditure (% of GDP) - India. s.l.:s.n.
- WRI, 2021. A Review of State Government Policies for Electric Mobility. s.l.:s.n.
- WRI, 2021. Procurement of Electric buses: Insights from TCO Analysis, s.l.: s.n.
- X-Fab, 2023. Automotive Semiconductors – a Foundry Perspective. s.l.:s.n.
- ZF, 2023. ZF makes magnet-free electric motor uniquely compact and competitive. s.l.:s.n.
- ZF, 2024. The Puzzles for the Best Electric Motors Solved.
- Zhang, Y., Zhong, M., Geng, N. & Jiang, Y., 2017. Forecasting electric vehicles sales with univariate and multivariate time series models: The case of China, s.l.: s.n.

Delhi Consultation (June 6, 2024)

Lotus Temple

Pune Consultation (May 22, 2024)

Aga Khan Palace

Chennai Consultation (June 22, 2024)

Palavakkam Beach

Bangalore Consultation (May 18, 2024)

Cubbon Park

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